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Evaluating Alternative Methodologies for Capturing As-Built Building Information Models (BIM) for Existing Facilities

Eddy Rojas, Carrie Dossick, and John Schaufelberger

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University of Washington
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under the supervision of

Beth A. Brucker, Project Manager (CEERD-CF-N)

Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Drive
Champaign, IL 61822

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Eddy Rojas, Carrie Dossick, and John Schaufelberger

University of Washington
Department of Construction Management
Seattle, WA 98195

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Abstract: The operation and maintenance of U.S. Army real property could greatly benefit from the availability of advanced forms of digital as-built facility data, such as those used in Building Information Modeling (BIM) systems. The Army Corps of Engineers requires the use of BIM on all new construction projects associated with the Army Standardization program. However, new construction typically accounts for only a small proportion of an installation's real property assets. Current BIM technology is capable of capturing existing facility data, but developing models for all existing facilities is not feasible because of the cost. As an alternative to developing complete models for existing facilities, a subset of BIM data could be developed to capture the data needed to improve the cost-effectiveness of operating and maintaining existing facilities. The University of Washington was contracted by the U.S. Army Research and Development Center under the Installation Technology Transfer Program to perform a comparative analysis of different methodologies for capturing as-built BIM data for existing facilities at Fort Lewis, WA. This report provides the results of that analysis.

Preface

This study was conducted for the U.S. Army Assistant Chief of Staff for Installation Management (ACSIM) under Installation Technology Transfer Program (ITTP) contract W9132T-08-2-0020. The ITTP Project Manager was Kelly M. Dilks, CEERD-CF-M.

The work was performed under the supervision of the Engineering Processes Branch (CF-N) of the Facilities Division (CF), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). The project manager and technical reviewer was Beth A. Brucker, Research Architect, CEERD-CF-N. At the time of publication, Donald K. Hicks was Chief, CEERD-CF-N; L. Michael Golish was Chief, CEERD-CF; and Martin J. Savoie was the Technical Director for Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Gary E. Johnston was the Commander and Executive Director of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
British thermal units (International Table)	1,055.056	joules
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

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Research Report Prepared

for

U. S. Army Engineer Research and Development Center
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Evaluating Alternative Methodologies for Capturing As-Built Building Information Models (BIM) for Existing Facilities

Introduction

There is a lack of intelligent digital data for effective support of improvements and/or maintenance of existing United States Army facilities. The U.S. Army Corps of Engineers has begun mandating the use of Building Information Modeling (BIM) for new construction to provide digital as-built data for facilities operation and maintenance. However, this only addresses new construction, which typically is a small portion of an installation's real property assets. Current BIM technology is capable of capturing existing facility data, but the cost would be prohibitive to develop models for all existing facilities. In lieu of a complete model, a subset of BIM data for existing facilities could be developed to capture the data needed for facility operation and maintenance. To address this issue, a study was undertaken by the University of Washington to conduct a comparative analysis of alternative methodologies for capturing as-built BIM data for existing facilities at Fort Lewis, Washington. This report provides the results of that study.

Scope of Work

The research objective was to identify efficient methods for capturing existing facility as-built BIM information by conducting a comparative analysis of alternative methodologies. The project was conducted in the following three phases:

Phase 1:

> ***Task 1.1***: The minimum required data fields needed to effectively manage the operations, maintenance, and asset management functions were identified in conjunction with the Directorate of Public Works (DPW).

Phase 2:

> ***Task 2.1***: Scenarios/methodologies were identified for collecting existing facility information.
>
> ***Task 2.2***: The economic analysis requirements needed for evaluation were identified.
>
> ***Task 2.3:*** The equipment/technologies that would be most efficient and appropriate for the evaluation were selected.
>
> ***Task 2.4:*** The field test (Task 3.1) was planned and coordinated.

Phase 3:

> ***Task 3.1***: Field tests for collecting as-built BIM information on a variety of facilities were conducted using selected equipment/technologies.
>
> ***Task 3.2***: A comparative analysis of the alternative methodologies and technologies was conducted.

Project Planning

Task 1.1 involved determination of the data collection requirements. The Construction Operations Building Information Exchange (COBIE) spreadsheets were evaluated and the Fort Lewis DPW staff were consulted. The following tabs were selected for use in data collection:

Tab 1 – Contacts	Tab 6 – Register
Tab 2 – Facility	Tab 7 – Component
Tab 3 – Floor	Tab 8 – Attributes
Tab 4 – Space	Tab 14 – Installation
Tab 5 – System	

Task 2.1 involved selection of the facilities and the type of equipment to be surveyed. The following buildings on Fort Lewis were selected for the field test:

- Building 3369 – New Company Headquarters
- Building 9137 – New Barracks
- Building 3218 – Multi-Use Facility (Administrative and Barracks)
- Building 11751 – New Company Headquarters

The equipment selected for the survey included:

Elevators	Sinks
Toilets	Urinals
Doors	Windows
Sump pumps	Water heaters
Air conditioning units	Generators
Boilers	Chillers
Fire alarm display panels	Sprinkler valves
Fire hose connections	Exhaust fans
Telephone panels	Switchgear
Air handling units	

Task 2.2 involved selection of the economic factors to be considered. Factors selected were the cost of the equipment and the productivity of the users.

Task 2.3 involved the selection of equipment to be used for conducting the field tests. After considerable investigation, it was decided to use the following:

- Week 1 – paper forms
- Week 2 – tablet personal computer with Access database
- Week 3 – Capturx for Microsoft Excel and Adapx digital pens
- Week 4 – handheld ultra-mobile personal computer with Access database

Task 2.4 involved the planning of the field test. A four-week field study was planned for the period 14 July 2008 to 8 August 2008 during which four different data collection technologies were to be used: paper forms, digital pens, a handheld tablet PC and an ultra-mobile PC. During the field test, field survey crews were selected to collect data to populate a COBIE Excel Workbook. The objective was to measure the efficiency of the survey crew on site as well as collect qualitative data regarding the crew's experience with the technology.

It was decided to use two graduate research assistants (GRA) and eight Field Research Assistants (FRA) to conduct the surveys. Each week two of the FRAs were trained on the use of one technology by one of the GRAs. After the training on Monday, the survey team collected data under the observation of a GRA. As noted above, four buildings on Fort Lewis were selected for the field test.

Building 3369, a company headquarters building, was used for the training on Mondays. On Tuesdays, the field survey teams collected data on Building 9371, which was a fairly new barracks. On Wednesdays, the teams collected data on Building 3218, which was a multi-use facility, with administrative spaces on the first floor and two floors of dorm rooms above. On Thursdays, the teams collected data on Building 11751, a company headquarters building. On Fridays, a post-survey assessment was made, and the teams were provided with an opportunity to work with the other technologies. The daily schedules are shown in Figures 1 and 2.

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
8:00 AM	Meet at Ft Lewis Visitor's Center	Report to GRA at Bldg 2012, Fort Lewis			
9:00 AM	Training Brief Pre-Survey Workload Assessment Safety Briefing	**Bldg 9371**	**Bldg 3218**	**Bldg 11751**	Post-Survey Workload Assessment, Questionnaire, and Discussion
10:00 AM		Field Survey (2-3 Tasks)			
11:00 AM	Lunch				Lunch
11:30 AM		Lunch			
12:00 PM	On-Site Training, **Bldg 3369** Post Processing (if applicable)				Alternative Tech Trials, **Bldg 2012** Alt Tech Questionnaire & Workload Assessment
12:30 PM		Field Survey Continues (2-3 Tasks) Post processing (if applicable)			
1:00 PM					
2:00 PM					
2:30 PM					Released
3:00 PM	Released				
4:00 PM		Released			

Figure 1. Daily Work Schedule (Paper, Tablet PC, and Handheld PC Methods).

	Monday	Tuesday	Wednesday	Thursday	Friday
8:00 AM	Meet at Ft Lewis Visitor's Center	Report to GRA at Bldg 2012, Fort Lewis			
9:00 AM	Training Brief Pre-Survey Workload Assessment Safety Briefing	**Bldg 9371**	**Bldg 3218**	**Bldg 11751**	Post-Survey Workload Assessment, Questionnaire, and Discussion
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11:30 AM		Lunch			
12:00 PM	On-Site Training, **Bldg 3369** Post Processing (if applicable)				Alternative Tech Trials, **Bldg 2012** Alt Tech Questionnaire & Workload Assessment
12:30 PM		Field Survey Continues (2-3 Tasks)			
1:00 PM					
2:00 PM					
2:30 PM	Travel to Adapx Office for Data Processing (Downtown Seattle)				Released
3:00 PM					
3:30 PM	Data Processing Training	Data Processing			
4:00 PM					
5:00 PM		Released			

Figure 2. Daily Work Schedule (Adapx Digital Pen Method).

The survey sequence selected for each building was:

- Primary mechanical room (1.5 hours)
- Storage/multifunction areas (1 hour)
- Ingress/Egress spaces: stairs and elevators (0.5 hour)
- Sample corridor with offices (1.5 hours)
- Sample corridor with bathrooms (1.5 hours)

A GRA was used to conduct a pre-survey of each building using plans provided by the Fort Lewis DPW. The purpose of the pre-survey was to identify preliminary data for Tabs 1 through 7 for the COBIE spreadsheets. The FRAs then completed Tabs 4, 7, 8 and 14 during the survey. In addition to the collection technology used, each survey team was given a common set of tools, which included two Hilti laser-measuring devices, 25-foot metal tape measure, flashlight, solar-powered scientific calculator, wet-wipes (to clean component tags of dirt or oil), pens, pencils, and clipboards.

Data for Buildings 3369 and 9137 were preloaded from 100% design drawings. The preloaded data included Tabs 1 through 6. The components that were preloaded included doors, windows, plumbing fixtures, and equipment from the mechanical, plumbing, electrical, and life safety schedules. Building 3128 had Tabs 1, 3, 5, and 6 preloaded. No spaces or component data were preloaded for this building. Building 11751 had Tabs 1 through 6 preloaded, and the components included doors, windows, and common plumbing fixtures. In none of the buildings was the data complete. There were components that had to be added for each building by the survey team.

Field Testing

Task 3.1 involved the field testing of the alternative technologies. On the first day of each week, the field research team received training which was followed by measured field surveys.

Initial Training

COBIE Spreadsheet Tabs. Each team was introduced to the COBIE paper spreadsheets and the relationship between four spreadsheet tabs, in the following order of dependency. The teams were instructed on which pieces of information on each spreadsheet they needed to gather from the field.

- Tab 4 – Space
- Tab 7 – Component
- Tab 14 – Installation
- Tab 8 – Attributes

Component Examples. Printed copies of PowerPoint slides, containing a list and some photos of common building components was also used as a training tool. The GRAs informed the teams that they would help guide the surveyors to determine which components needed to be accounted for, since the methodology (not the students' knowledge of facilities) was being tested. The teams were also exposed to using the Hilti laser-measuring tool, which lists up to three linear measurements at a time.

Attribute Data Sheets. Paper forms to capture component attribute information were available to all teams during the four-week study. The attribute sheets were either forms being used by the DPW or from the Industry Foundation Classes (IFC) standards. The IFC standards were developed by the International Alliance for Interoperability (IAI) and used in this study subsequent to the U.S. Army Corps of Engineers progression toward Building Information Modeling (BIM). Attribute data sheets were available for the following component types: door, window, shower, sink, toilet, urinal, stairs, drinking fountain, heat sensor, smoke sensor, electrical distribution point, pressure reducer, double check valve, switch gear, and transformer.

Additional Reference Material. Paper copies of each facility's floor plans, a mapped key of preloaded components, the list of OMNI Classes, and Tab 6 (Register) were also provided to the FRAs for reference. The OMNI Class was a field required for new entries on Tab 4 (Space). Tab 6 (Register) was a static pick-list that was used for new entries on Tab 7 (Component).

Field Study – Week One

Introduction

Week One of the field trials ran from 14 July 2008 to 18 July 2008 following the standard schedule in Figure 1. The technology and methodology for that week was a two-phase process that involved collecting data in the field with paper forms, followed by computer data entry in an office setting. The technology had two primary components, paper forms that were filled out by using a pen/pencil and data entered into the COBIE Excel Workbook using a desktop computer.

The FRAs used two types of forms for the field surveys which were the four COBIE Excel tabs printed on 11-inch by 17-inch sheets and the component attribute forms printed on standard 8.5-inch by 11-inch sheets. Pens, pencils, highlighters, paper clips, standard 9-inch by 12-inch clipboards, and other accessories that were deemed necessary to conduct the field surveys were provided upon the FRAs' request.

At the end of each day, the team transposed the information collected from their paper forms to an electronic file of the COBIE Excel spreadsheets. The FRAs shared a single desktop Dell Optiplex Gx620 computer, equipped with a 17-inch LCD screen, standard keyboard, and optical mouse. The computer was configured with a Microsoft XP operating system and loaded with the Office 2003 Professional Suite.

Description of Work Processes

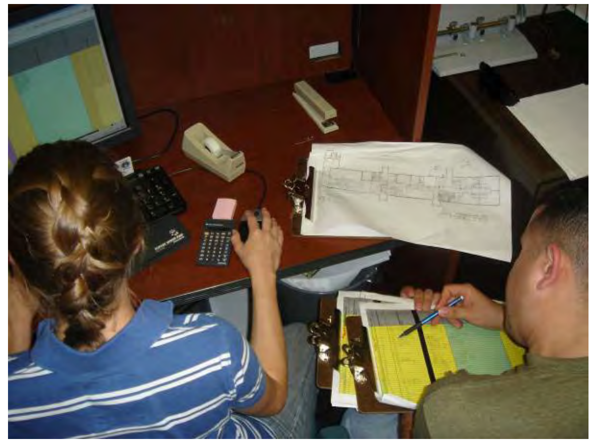
After the initial training day on 14 July 2008, when the team practiced using the paper spreadsheets and determined what accessories they needed to effectively perform their tasks, they decided to use a separate clipboard for each of Tabs 4 (Space), 7 (Component), and 14 (Installation). Blank sheets of Tab 8 (Attributes) were available each day, but remained unused. Instead, the FRAs made an early decision to use only the Attribute data sheets in the field and transpose the information to the COBIE Excel spreadsheets during the data entry phase later in the day.

The team initially completed each of the tabs and Attribute sheets together during their training session, as they continued to solidify their understanding of the relationship between the spreadsheets and the information they were required to collect. By the first day of surveying, the team divided responsibilities. One team member typically controlled Tabs 4 (Space) and 7 (Component), while the other controlled Tab 14 (Installation) and the measuring devices. The team decided early on the first survey day that measurements should always be conducted by the same person, so as to maintain a consistent rounding factor, while the other person took dictation of the measurements. There was an amount of task sharing, as the two members of the team continued to assist one another with any measurements for the gross area of the space or to complete the Attribute data sheets if their workload permitted. However, the responsibilities were not static and, for a portion of Day Two, the FRA controlling Tabs 4 and 7 also took responsibility of Tab 14.

The field surveys were generally conducted on a room-by-room basis, collecting component, installation, and attribute data per identified space. The team first referenced the floor plans to identify the space they were surveying. The FRA who was in control of Tab 4 (Space) would search the preloaded information on the paper forms to see if the space was already entered on the spreadsheet. If the space could not be found, the FRA would add the entry to an empty row on the sheet, including the appropriate OMNI classification. For both preloaded and newly written entries, the second FRA would measure and call out the height, width, and length of the room. The FRA in charge of Tab 4 (Space) copied the spatial measurements in a spiral notebook, intending to compute the areas later during the data entry phase. By the second day of surveying, the team also decided to call out measurements in a standard format (i.e. width is first measured, followed by height) so they could easily recall the specific configuration from their notes.

Preloaded information on Tab 7 (Component) was difficult for the team members to locate because components appeared in the spreadsheets according to component type. As a result, a room’s door may be on the first page of Tab 7 (Component), while the windows of that room may appear on the third page. To cope with this issue, the person in charge of Tab 7 (Component) visually scanned all preprinted information for any components associated with the Space ID they were surveying at the moment. These components were called out to the person controlling the Tab 14 (Installation) paper form, who then collected information on Tab 14 and the Attribute data sheets for those components. In the meantime, the first team member would enter any additional components in the next empty row on Tab 7, including the appropriate Register ID, and assist the second member with the Attribute data sheets if needed.

One Attribute data sheet was used for each component. At one point on the last day of surveying, the team ran out of door attribute data sheets and the supervising GRA suggested that, by drawing vertical gridlines across the different attribute fields, information on multiple doors could be entered on one data sheet. The team tried this tactic on the first day of surveying, when they realized that the window in one dorm room was exactly the same window in the next room. One FRA looked for the previously used Window datasheet, intending to annotate the room numbers on the data sheet, but could not find the previously filled sheet. The team ultimately filled a fresh attribute sheet, and also abandoned the idea of recording multiple components on one data sheet because it disrupted their process of surveying all the components on a room-by-room basis. However, as the week progressed and they became more confident in their surveying skills, the team realized that using a single Attribute sheet to collect information on multiple components could have improved their efficiency in the field.



At least two hours were reserved at the end of each day for the team to transpose the data they had collected to an electronic COBIE Excel spreadsheet. The team entered data on a tab-by-tab basis. While one FRA called out information from the paper forms, the other would type the information into the spreadsheet. The FRA who was calling out the information would also provide quality control for what was being typed, catching typos and correcting any miscommunications. Since the team also only captured raw spatial measurements in the field, they spent a considerable amount of time computing the gross square footage required in Tab 4 (Space) during the data entry portion of the day. At the beginning of the first data entry task, the team used a scientific solar calculator (single-line display) for their computations, which was time-consuming and resulted in multiple errors. The team's productivity increased when they adopted using a secondary Excel spreadsheet as a calculator, to more efficiently and accurately compute areas. Even so, the small amount of data the team collected for the third task of Day One consumed over ten minutes to compute.

Issues Encountered

<u>Logistics and Site Issues.</u>

- *Writing ergonomics.* Locating an area where the survey team could comfortably write information and layout their materials was a challenge. The FRAs were very grateful for areas that were equipped with a table and/or chair.

- *Room access.* Access inside certain barracks rooms and locked offices was not possible, even with the presence of facility escorts. Either lock combinations did not work as expected or the facility escorts were, themselves, not granted access into the rooms.

- *Facility occupant awareness.* The facility occupants' lack of knowledge of the study resulted in delays during Week One. The GRA needed to explain the general purpose and timeline of the study at the beginning of each survey day from 15-17 July 2008 to the occupants, prior to the surveys commencing in each new facility.

- *Lighting levels.* Some of the component tags could not be clearly deciphered due to low light levels. A flashlight with a stronger or paler light would have been useful.

- *Height restrictions.* Some component tags could not be read due to the height of the equipment. The FRAs used a digital camera to take a picture of the component tag, and then used the zoom-in function on the camera screen to collect the information for Tab 14 (Installation).

- *Incorrect or lack of data plates on components.* In general, data plates on doors were painted over and impossible to get information from even in the newer buildings that were surveyed. In a few cases, equipment in the mechanical rooms was mislabeled or lacked information.

Technology/COBIE Issues.

- *Locating preloaded data.* The team experienced initial difficulty in making the preloaded information useful, but towards the end of the first survey day, they developed a system in which they first located in which room they were by referencing the floor plans, then one team member would scan Tab 4 (Space) for the room and Tab 7 (Component) for any components associated with that room.

- *Pencils versus pens.* The FRAs requested pencils for the surveys because they anticipated making many errors and found it difficult to read data sheets full of erroneous pen entries that had been crossed out and rewritten. Pencils, however, also presented a latent issue, in that the graphite script sometimes smudged and proved difficult to read by the end of the day.

- *Script recognition.* The FRAs had difficulty in deciphering each other's hand written notes on the paper forms. During the data entry portion, the FRA who was reading the information had to ask for clarification of their partner's handwriting.

- *Naming convention of data.* The team would sometimes get confused in how a component should be named. For example, two recurring questions were how to determine to which space a door belonged, and what to name unique components in a mechanical room. The preloaded data used an abbreviation of three letters for the component name, coupled with a number that identified the room or serial quantity. However, the team suggested that a clearly written protocol and/or a list of standardized component abbreviations be available for reference.

- *Management of COBIE information and Attribute data sheets.* The team occasionally failed to label attribute sheets or to relate the proper information (Space ID, Component ID, or Installation ID) between tabs. This caused a loss in productivity during data processing and increased the potential for errors. The team experienced problems in recalling which components related to their data and would probably have to revisit the survey sites in question.

- *Shortage of Attribute data sheets.* As the team became more efficient during the week, they used up more Door Attribute data sheets than was expected. To compensate, the team used one form for multiple components of similar type.

- *Clipboards.* Management of the multiple clipboards was a challenge. The FRAs clipped the boards to each other so that they could carry multiple tabs; however, they would still experience all the paper slipping from the clipboards and falling to the ground at least once a day. The other potential issue with the clipboards was their relative small size compared to the 11 inch by 17 inch COBIE paper spreadsheets, but since the FRAs did not use the cells on the far right of the spreadsheet, this proved to be a non-issue.

- *Inefficiency of OMNI class paper reference.* The OMNI class reference was over 30 pages and extremely difficult for the FRAs to use. One of the team members highlighted the main categories for the OMNI classes to facilitate the search process, but this was a small improvement. The FRAs suggested that a "common list" of typical OMNI classes would be useful. Ultimately, the team decided to run a computer-assisted search of the OMNI class during the data entry phase.

- *Computing gross square footage areas.* This requirement for Tab 4 (Space) could be expedited if pure dimensions were required on a different form, or if a measuring device that automatically computed areas was utilized

- *Use of separate notepad and calculator vs. scratch Excel Sheet.* The team was very slow and made many mathematical errors in trying to use a single-line display solar calculator to compute the gross square footage. The supervising GRA trained the team how an Excel spreadsheet could be configured and used to increase efficiency and accuracy of these calculations. A device that can compute square footages while in the field would have been useful.

- *Paper COBIE spreadsheet design.*

    - Size of cells: The cell size for the 11-inch by 17-inch COBIE spreadsheets may have been too small, especially if the surveyor needed to cross out erroneously entered information.

    - The cells that must be completed by the team should be colored or distinguished. The team did not fill out certain pieces of information on the paper forms, such as Register ID, and would also forget to fill that information in the electronic COBIE spreadsheet.

- *Electronic COBIE Spreadsheet design.*

  - The team experienced difficulty using the pick list in Tab 14 (Installation) and found that the pick-list scroll was inefficient in finding the appropriate component. The FRAs suggested it would be useful if the spreadsheet cells tried to find the best fit (auto-fill) based on what was being typed into the cell.

  - The team did not have to fill out the repetitive information, such as “Created By” in the different paper tabs because they planned and successfully used the copy/paste hot keys or fill-down function in Excel to fill the repetitive information.

  - The team had to figure out how to copy/paste Component ID for components after row 200. This is a limitation with the COBIE spreadsheet, and the data entry personnel need to have a good understanding of the tab relationships and application limitations to understand why an otherwise properly entered component may not appear on a pick-list for the next related tab.

- *Attribute data sheet design.*

  - The FRAs could not gather the majority of the Attributes for the components in the field, due to the lack of available information. The data sheets did not collect some information that one might consider important, such as the width and height of a door and of what material it was composed.

  - Attribute data sheets lacked a space reserved for the Installation ID, resulting in members forgetting to label the sheets.

<u>Productivity Related Issues.</u>

- *Preloaded data versus new entries.* The FRAs expressed that it was easier to make new entries as they surveyed a building, as opposed to locating preloaded data that had been entered on the spreadsheet by a third party.

- *Misplacement of survey tools.* On the afternoon of Day One, the FRAs misplaced the paper notebooks/references. They spent ten minutes trying to find the notebooks in previously surveyed areas or in their vehicles before realizing that the materials were hidden from sight behind one of the doors in the area. Throughout the week, the FRAs also lost productivity when they did not secure their other survey tools (measuring devices, pencils) on their person.

- *Necessary work breaks.* Breaks were provided regularly between field and data entry tasks. Surprisingly, the team appeared to be more in need of regular breaks during data entry, rather than in the field. In the field, when the team was given a break between tasks, they took time to walk or stand outside of the facility, but would often return well within the suggested break time. When the team returned, they often looked refreshed and determined to begin the next task. In contrast, when the team was given a break between data entry tasks, the team would extend their breaks beyond the suggested time, sometimes complaining of fatigued eyes or a stiff back.

- *Physical impact of weather.* Temperatures were in the high 80's during Week One. By the end of the field survey portion of Day One, the team complained of headaches, likely from dehydration. For the remainder of the week, the GRA ensured the FRAs took longer breaks and encouraged them to drink more water.

- *Accuracy of floor plans.* The team's productivity slowed tremendously when the floor plans did not match existing conditions.

- *Questionable necessity to collect some data in the field.* The FRA conducting data entry filled all the component description information on Tab 7 (Component) without the help of the other FRA reading out the information. The purpose/function of the component was obvious to the FRA, so time spent in the field to write such information may have been wasted. However, this information would not be transparent to a data entry person who is completely segregated from the field data collection phase.

- *Microsoft Excel issues.* Considering the density of information in the spreadsheet, the FRAs would inadvertently enter data in the wrong cell. On a few occasions, the FRAs accidentally activated a split-screen view, which was disorienting and disrupted the team's momentum of data entry.

- *Impact of Attribute data sheets on productivity.* Mechanical rooms were unexpectedly the spaces in which the FRAs were the fastest in surveying. Few of the mechanical components had attribute data sheets and those that did, such as a deluge valve or electrical distribution panel, had only 1-5 attributes. However, common components (e.g. doors, windows) had anywhere from 8-21 different attributes each.

Observer Reflections

- Cognitive comfort level of surveyors: Both FRAs for Week One were inexperienced in performing this type of survey, especially in collecting and computing spatial information. The FRAs concentrated more on performing the tasks completely and correctly, rather than collecting as much information as possible in the allotted time.

- The team had difficulty determining how to complete the COBIE spreadsheets for Day Two, when no preloaded data was printed on the sheet. An example line of data for each tab would be useful in this situation.

- The paper method would likely be less efficient if conducted by a single person, rather than by a two-person survey team. Neither of the FRAs from Week One were ever idle in the field, as they could assist one another in gathering Attribute information, provide quality control, or continue surveying the next area.

- Data entry could possibly be performed by an administrative person; however, this could compromise data integrity. An administrative data entry person would not have the same intimate knowledge, or the quality control, of data entered by the two-person field team.

- One FRA was considerably faster in data entry that the other FRA. The comfort personnel have in using Microsoft Excel short-cut “hot keys” to copy and paste values between cells, as well as their general familiarity with Excel, is a very important factor in productivity rates for data entry.

- It took the team nearly as long to collect the field information as it did for them to perform data entry. In the field, the team practiced shortcuts, such as not filling the Created By cells, not computing the gross square footage, and not having to find the exact OMNI class name. In the office, having to fill in these cells, plus manually transpose the Attribute data fields and values into the sheet, consumed a substantial amount of time. The data entry could eventually be expedited by copying/pasting the attribute names for similar component types, but this also required the FRAs to keep track of which rows in Tab 8 (Attributes) were for which component type. However, when the team did not have to enter much data for Attributes, such as the case for mechanical rooms, the FRAs were able to complete most of the data entry task.

Field Study - Week Two

Introduction

Week Two of the field trials ran from 21 July 2008 to 25 July 2008 following the standard schedule in Figure 1. The technology and methodology utilized that week was a Microsoft Access database used on an Acer TravelMate C300 laptop. The Acer laptop featured the following:

- Microsoft Windows XP Tablet PC Edition
- Office 2007 Professional Suite
- Intel Centrino Pentium-M 1.5GHz
- Weight 6.23 lbs
- Battery Run Time 4 hours
- 4-in-1 card reader

- Display Type 14. 1" TFT active matrix
- Max Resolution 1024 x 768 (XGA)
- 4-way scroll button, digital pen
- RAM Installed 512 MB / 2 GB (max)
- Hard Drive 40 GB

The Microsoft Access database was structured from the COBIE spreadsheet with forms for Tabs 4 (Space), 7 (Component), 8 (Attributes), and 14 (Installation). The user interface consisted of a menu with a button to select each of the four tabs. A form would then open for that specific tab in which the user could enter the appropriate data using the form.

The same paper Attribute forms that were utilized in Week One were also available to the FRAs; however, the COBIE paper spreadsheets were not made available in Week Two. Pens, pencils, highlighters, paper clips, standard 9-inch by 12-inch clipboards, notepads, and other accessories that were deemed necessary to conduct the field surveys were provided upon the FRAs' request.

Description of Work Processes

After the initial training day on 21 July 2008, the team divided survey responsibilities into two roles: data collection and data entry. The data collection FRA was responsible for recording all measurements, providing component and installation information in verbal and/or written format, and filling the Attribute data sheets. The data entry FRA fully managed the Access database on the ACER laptop and performed quality control over the information provided by the data collection FRA.

From the very start of the hands-on training session, the FRAs assumed their divided roles, with the data entry FRA acting as the pace setter and providing direction for the team. Although this enabled the team to immediately start performing their tasks, the lack of communication and swift geographic separation of the team soon became the source of frustration between the team members. During the week, the data entry FRA always found a stationary location, either seated at a table or on the floor, to set-up the laptop and begin working on the database. In most cases, the data collection FRA staged the two bags, containing the survey tools and Attribute data sheets, in the most convenient area where the survey was to be performed and was constantly mobile. On Day Two of the survey, the data collection FRA was able to utilize an unused television cart as a mobile workstation, which he deemed as the ideal set-up for his tasks. The FRA was able to stand and use the cart as a writing surface, while keeping the survey forms and tools on a lower shelf and within convenient reach.

Since the data collection FRA did not have the COBIE paper spreadsheets, blank notepad sheets were used to record information for Tabs 7 (Component) and 14 (Installation) in normally occupied spaces. The repetitive task of essentially recreating the Tab 14 (Installation) headings on blank notepad sheets was later revealed as a source of frustration for the FRA, which could have been alleviated, had a paper copy of the COBIE tabs had been provided to the Week Two team. However, for mechanical spaces, the data entry FRA preferred to directly enter information into Tab 7 (Component) of the Access database as his teammate called out the component and installation information.

At first, the team collected Attribute data on a space-by-space basis, but both team members soon determined that using one Attribute data sheet for multiple but similar-typed components was easier for both data collection and data entry. Fewer paper forms reduced the number of times the data collector needed to retrieve a new Attribute data sheet and were physically easier to manage. By the afternoon of the Day One, the data collection FRA was conducting surveys based on component type, visiting each space several times as information on a different type of component was collected.

As the week progressed, each team member gained insight on how to most efficiently use their own set of tools. However, poor communication between the team members and the data collector's lack of understanding of the electronic database created tension in the team. Each FRA perceived that they owned the most difficult task, and the members grew frustrated over the procedural demands their partner placed on them. The data entry FRA found the most efficient process for him was to enter all data for one tab before moving to the next tab; however, the data collector wanted the flexibility and autonomy to collect the data by component type or on a space-by-space basis. On Day Three of the surveys, and after a particularly difficult morning of miscommunication, the two FRAs were able to fully understand and appreciate what the other team member required. Although the team had previously discussed how they would perform the survey, they refined their process to the following sequence and performed with greater success during the last day of surveying:

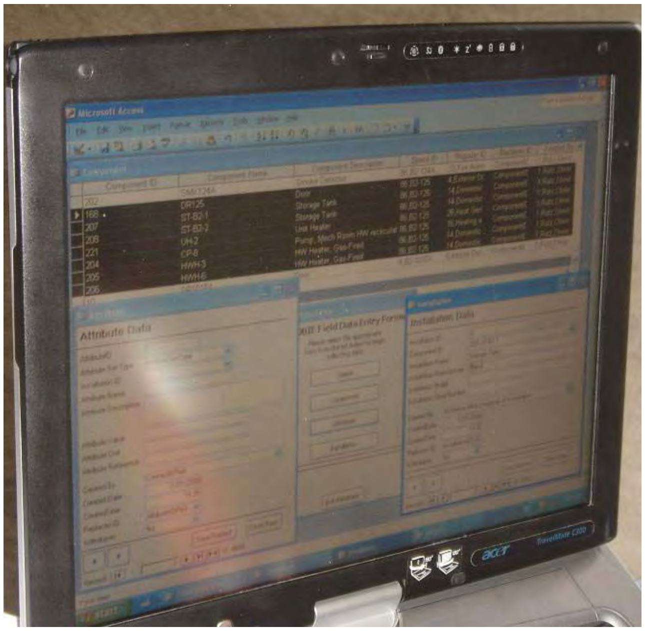
- *Physical verification of spaces.* Both team members would perform a walk through with the paper floor plans and verify all accessible rooms. This step enabled the data entry FRA, who was otherwise stationary, to become acquainted with all the spaces and perform some quality control over the data that would be submitted to him.

- *Verification/Addition of spaces in database.* Based on first-hand knowledge, the data entry FRA would ensure the spaces were loaded in the database and add new entries to Tab 4 (Space), as required.

- *Measurement of spaces.* The data collector would provide the data entry FRA raw measurements for one or two spaces at a time. The data entry FRA would then use an Excel spreadsheet or a calculator to compute the gross square footage of the space, and then enter the value in the database.

- *Report components within spaces.* If possible, after completing all measurements, the data collector would report to the other FRA what components existed in each space. This was, actually, an imperative step within mechanical spaces if the data entry FRA intended to keep up with the pace in which the data collector submitted information.

- *Collect installation and attribute information per component type.* The data collector would return to all the spaces and collect the installation information and attributes for a single type of component. The information for five doors, which may all belong to different spaces, would be captured on a single Attribute data sheet and then submitted to the data entry FRA. This step would be repeated until all types of components were collected and entered into the database.



Preloaded information on Tab 7 (Component) was initially inefficient for the data entry FRA to use because, as with the team for Week One, it was difficult to locate all the components associated with a space. Since Day One of the survey involved working with both preloaded data and adding new entries to the database, it was a highly frustrating experience for the data entry FRA. In contrast, the data collector FRA had a relatively easy first day, with the exception of being confused over what information needed to be collected in the Attribute data sheets. During Day Two, working with no preloaded data, the data entry FRA's productivity seemed to increase. In the process of working with the tool, he also grew comfortable with keeping multiple tab forms open and toggling between the Datasheet (traditional spreadsheet) and Design (data form layout) view of the Access database. By Day Three, when he had preloaded data to work with again, the FRA understood how to effectively use the Access form and commented that the preloaded data probably saved at least an hour's worth of data entry.

Issues Encountered

<u>Logistics and Site Issues.</u>

- *Data entry ergonomics.* Locating an area where the data entry FRA could organize the incoming data sheets and type information into the database was a challenge. If a table and/or chair was not available for the data entry FRA, he sat on the ground and showed visible discomfort after an hour-long task.

- *Data collection ergonomics.* The data collection FRA found it difficult to manage his notebook, the Attribute data sheets, and the surveying tools, especially since he was constantly moving between spaces and submitting information to his fellow team member. The surveyor was fatigued from repetitive and constant movements, such as bending down to reach the survey tools/sheets, opening doors, walking to/from the location of the data entry FRA, and packing/unpacking between tasks. The FRA strongly recommended the fabrication of a mobile workstation to address the ergonomic issues involved in data collection.

- *Room access.* The team experienced new access issues on Day Three because they were collecting information at a faster rate than the first week's team and, therefore, entering more spaces. The facility used for Day Three was a new company headquarters with many activated cipher locks. The GRA was able to open each locked space at the data collector's request, but was not able to keep the space unlocked for the duration of the survey. This issue negatively impacted the productivity of the data collector, who would possibly make multiple trips to the same space.

- *Lighting levels.* Some of the component tags could not be clearly deciphered due to low light levels. The data collection FRA later recommended the addition of an LED flashlight for the tools used by future survey teams.

- *Height restrictions.* Like the first week's survey team, the FRAs in Week Two used a digital camera to take pictures of highly elevated components, and then used the zoom-in function on the camera screen to collect the information for Tab 14 (Installation). However, in some cases, the digital photograph of the component tag was still illegible.

- *Incorrect or lack of data plates on components.* In general, data plates on doors were painted over and impossible to get information from even in some of the newer buildings that were surveyed. In a few cases, equipment in the mechanical rooms was mislabeled or lacked information.

Technology/COBIE Issues.

- *Utilizing preloaded data.* The data entry FRA displayed initial difficulty in making the preloaded information useful but, after working with the Access forms and Datasheet views for two days, found that preloaded component data saved a substantial amount of time. By scanning the information in the database via Datasheet view, the FRA did not have to painstakingly scroll through the pick-list in Design (form) view, and could easily determine what components already existed in the database.

- *Naming convention of data.* Similar to the first week's team, the team for Week Two would occasionally get confused in how a component should be named and how they should abbreviated a component name.

- *Management of Access database forms.* The data entry FRA experienced difficulty in grasping the relationship between the COBIE tabs, but was able to overcome this when he realized that multiple Access forms (COBIE tabs) could be viewed simultaneously.

- *Shortage of Attribute data sheets.* Although the data collector practiced using a single Attribute data sheet to record information on multiple components of similar type, he still was faced with a shortage of data sheets. The GRA had underestimated the progress the PC technology team would make, especially since they moved at an increasingly faster rate than the first week's team. To compensate, the team copied the Attribute data sheet headings onto a blank notepad sheet.

- *Efficient use of OMNI class electronic file.* An electronic file of the OMNI class reference was made available on the Acer laptop. The data entry FRA was able to run a query within the electronic file and locate the classification for newly entered spaces.

- *Computing gross square footage areas.* The data collection FRA initially attempted to compute square footages, but his high error rate in using a single-line calculator compelled the data entry FRA to take over the computations. The data entry FRA was equipped to use Excel spreadsheets to more accurately and efficiently compute gross areas and some dimensional Attribute information (e.g. glazing area factor for windows).

- *Inefficiency from lack of paper COBIE tabs.* Depriving the data collection FRA from utilizing paper copies of COBIE Tabs 7 (Component) and 14 (Installation) only resulted in the FRA creating make-shift forms in the field. The data collector also often forgot to gather component and installation information prior to completing the Attribute data sheets. Only in the mechanical room was the data entry FRA able to directly enter component and installation information into the database with the data collector.

- C*OBIE Access forms design.*

    - Like the first week's team, the data entry FRA for Week Two experienced difficulty using the pick list in the Tab 14 (Installation) form. The FRA preferred to type in data and have the Access form suggest a best fit or at least bring the pick-list closer to the desired value, which would have been a useful feature for a variety of fields, to include Created By, Space ID, Register ID, and Attribute Names. Instead, the FRA had to use the pick-list to ensure the integrity of inter-tab relationships.

    - The data entry FRA attempted to change certain values while accessing the Datasheet view. However, typing data in cells that were linked from different forms (e.g. opening Tab 7 in Datasheet view but trying to change the Tab 4 (Space) would often cause the Access application to freeze. The data entry FRA had to exit Access for the form to unlock, which resulted in a loss of productivity.

    - The Attribute data sheets were extremely difficult for the data entry FRA to process. Even when utilizing the Datasheet view in Access, multiple rows could not be copied and pasted (a limitation of Access). Additionally, the FRA was required to recall which row number contained the last data entry, or he would chance overwriting existing information in lower numbered rows. Considering these complications, the survey team maintained a neat stack of filled Attribute sheets but did not make a serious attempt to process the information in the field. The data entry FRA was able to keep up with the data collector for Tabs 4 (Space), 7 (Component), and 14 (Installation), but strongly recommended processing of the Attribute sheets in a more comfortable office environment.

    - The team had to learn how to copy/paste the Component ID for components after row 200, just as was required of the first week's team. The format of the Access forms appeared to help the data entry personnel gain a quicker understanding of the tab relationships than their predecessor team.

- *Attribute data sheet design.*

    - The team for Week Two expressed their dissatisfaction with the Attribute data sheets. The data collection FRA had work experience in the construction management field and was still confused by the information requested on the Attribute data sheets. Aside from the majority of information being unavailable from field observations, the terminology did not follow U.S. industry standards.

    - Attribute data sheets lacked a space reserved for the Installation ID, resulting in the data collector forgetting to label the sheets. Additionally, since the FRA was sometimes using the Attribute data sheet to record installation information, it would have been useful to reserve spaces for manufacturer, model, and serial numbers.

<u>Productivity Related Issues.</u>

- *Management of survey tools.* The ergonomic difficulties discussed in the logistic/site issues section negatively impacted the team's productivity.

- *Necessary work breaks.* After the survey team completed each hour-long task and moved to the next task, they were provided a ten-minute break. The data entry FRA looked especially tired after each task and probably could have benefited from longer breaks, but he encouraged his partner to press forward to the next task. As the day progressed, the data collector expressed his general fatigue, while the data entry FRA complained of sore eyes and a stiff back.

- *Physical impact of weather.* Temperatures were in the low 70's during Week Two. On Day Two, after the data entry FRA spent two hour-long tasks sitting in breezy entry vestibules, he complained of numbness in his hands and feet due to cold. The FRA relocated to an internal conference room for the rest of the day, but it appeared he had already caught a minor head cold from the exposure.

- *Accuracy of floor plans.* The team's productivity slowed when the floor plans did not match existing conditions during survey Day Two; however, the data collection FRA was able to confidently correct the floor plan discrepancies to match true conditions.

- *Impact of Attribute data sheets on productivity.* Mechanical rooms were the fastest spaces for the FRAs to survey because few of the mechanical components had attribute data sheets. Since the team members were in the same room, the data collection FRA was able to audibly list the components within the mechanical room, and the read the component tags aloud for the data entry FRA to directly enter into the database.

Observer Reflections

- *Preconceptions of surveyors.* Both surveyors for Week Two had some level of experience in facility maintenance and had preconceptions of what tasks they would be performing. The surveyors were very frustrated with the inefficiencies and limitations of the tools they were using, which negatively impacted their energy levels, but resulted in valuable suggestions for process improvements.

- *Miscommunication between vastly different roles.* The demands of each FRAs very different responsibilities were long under-appreciated by their FRA partner. Ensuring each team member understands the COBIE tabs and relationships, as well as the physically tiring aspects of data collection, is an important training step to attain healthy team dynamics.

- *Need for team effort.* The Acer laptop method could be performed by a single person; however, productivity levels would likely be much lower than a two-person survey team. The surveyors cited that, by working in a two person team, they motivated one another, provided quality control of each other's work, and were sometimes able to directly feed information into the database. The instances where only one team member was productively engaged was a result of the data entry FRA attempting to process Attribute data sheets in the field.

Field Study – Week Three

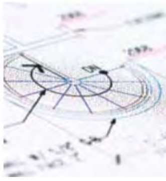
Introduction

Week Three of the field trials ran from 28 July 2008 to 1 August 2008 utilizing the standard schedule in Figure 2. The technology and methodology utilized this week was Capturx for Microsoft Excel and digital pen from Adapx, Inc. The technology has three primary components:

- Digital pen: *The field-ready digital pen writes with normal ink on paper while a sophisticated built-in sensor and image processor stores the annotations in memory.*

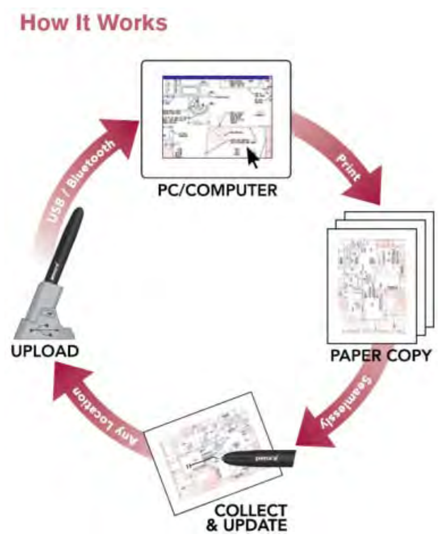
Digital Pen Specifications
Model: AMP-121 (USB and Bluetooth®)
Weight: 1.06oz
Dimensions: 6.02 x .75 x .6in (without cap), 6.18 x .83 x .71in (with cap)
Data communication: USB 1.1 standard (also supports USB 2.0 standard), Bluetooth® 1.2 standard
Built-in battery: Lithium-ion rechargeable battery
Continuous writing time: 2 hours (120 minutes) or longer
Standby time: 10 hours (min.) without a cap
Charging time: Approx. 2.5 hours (from zero to 100% charge)
Charging method: Dox cradle or USB adapter

- Digital paper: *Virtually any paper becomes Digital Paper by imprinting it with a special almost imperceptible dot pattern. A basic PostScript 4-color printer can print as much Digital Paper as you require on demand.*

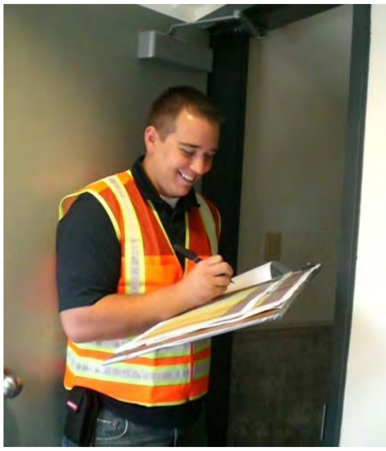


- Capturx software: *The digital ink from the pen is integrated with applications and uploads data via a USB docking station directly into Microsoft OneNote, ArcGIS 9.2, Autodesk Design Review, and Microsoft Excel.*

Source: http://www.adapx.com/images/pdfs/AdapxBrochure_vol.1.1_w.pdf

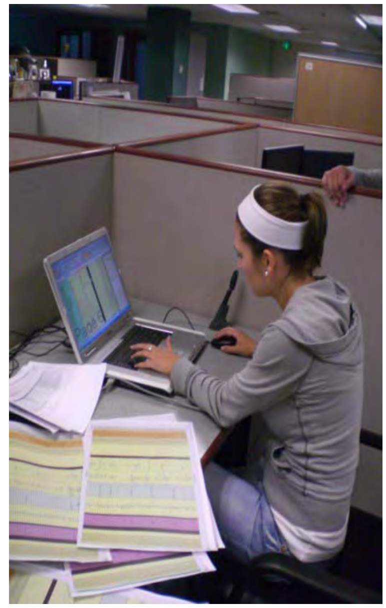


The package works together to electronically capture data from the field that is done with paper and ink that is very common in many of today's business practices. The Capturx enabled software prints a series of micro-dots in a unique pattern that makes every sheet unique. The digital pen then is able to read these dots allowing it to know its exact location on that sheet of paper and records what is written and drawn on that paper. This recording is the creation of digital ink which is store in the pen until it is docked at which time the data is uploaded to the correct software and file and page and automatically updates the file, saving time from entering all that data by hand at the end of the day.



Capturx for Microsoft Excel was still under development at the time of this field trial so all printing and downloading of the pens was done at the Adapx office. There were four tabs from the COBIE spreadsheet that were printed on 11-inch by 17-inch paper utilizing the same format from week 1. Those Tabs were 4 (Space), 7 (Component), 8 (Attributes) and 14 (Installation). In an effort to improve the efficiency of handwriting recognition, several lists within the spreadsheet built as a word list, a function of the Capturx plug-in. The word list constrains the handwriting recognition process to the list of possible answers that are listed in the word list. This was used for lists that were to have standard, repetitive inputs. The following items were built into word lists: Register ID, Created By, Space Usable Height Units, Interior Gross Area Unit, and Floor ID. Additionally, two numerical keys were initially designed to allow the FRAs to enter a number instead of writing out the entire entry. This was used for the Component ID and OmniClass13 from the additional pick list tab. The Component ID key was only built for the training building and was not available for use during the three survey buildings because each component list is specific to each building.

Description of Work Processes



The original plan was for the team of FRAs to have one digital pen to utilize. However, very early in their training at the training facility they requested to use two pens in an effort to speed up the process. A second pen was given to the team to utilize in their training and subsequent survey activities. Each FRA had a digital pen to use, and they carried the pre-printed COBIE spreadsheet on large custom clipboards. The clipboards were 14 inch by 19 inch in size made of 3/16-inch backing type material with three large binder clips for attaching paper to it. The FRAs each had two of the four tabs attached to their clipboard. This was a process selected early on by the team, which later became a restriction of the technology. Typically, one FRA would have Tabs 4 (Space) and 8 (Attributes) while the other would have Tabs 7 (Component) and 14 (Installation). The FRA with Tab 4 would start collecting spatial data while the other FRA would begin with Tab 7 by verifying if a component was pre-loaded or needed to be loaded. Then, they would complete Tab 14 for that component before moving on. After completing the spatial data collection, the first FRA would begin to work on Tab 8 starting with the component the other FRA started with and would follow in the same order. The team would typically start with the door in which they entered when gathering data on components. They then work through the space collecting in the data for all the various components, but they did not always utilize the same method in how they navigated through the room. At approximately 14:30, one of the FRA would drive to Seattle to the Adapx Inc. office to dock the pens with the assistance of the Adapx Inc. staff. The FRA conducted a quality check of the data downloaded and made any necessary corrections while being observed by a GRA.

Issues Encountered

<u>Logistics and Site Issues.</u>

- *Clipboards.* The team started with standard clipboards during training and asked for larger clipboards that were appropriate for 11 inch by 17 inch paper. Larger clipboards (14 inch by 19 inch) were fabricated that evening and made available to the team for the start of survey activities for Building 1 (9137).

- *Building and room access with Building 9137.* Escort was late delaying the start of task 2. After lunch, the escort was late again and delayed task 4 by five minutes.

- *Building and room access with Building 11751.* The survey was delayed between task one and task two, due to having to find the corresponding door for the key available to the GRA. Additional delays were experienced in determining cipher lock codes within the facility.

- *Incorrect or lack of data plates on components.* In general, data plates on doors were painted over and impossible to get information from even in some of the newer buildings that were surveyed.

<u>Technology/COBIE Issues</u>

- *Adapx digital pen power-charging.* The pens were not charged the night of day two so the team had to take a little longer lunch while surveying Building 3218 into order to charge the pens on the desktop at the office.

- *Capturx for Microsoft Excel.* The software cannot process more than one pen per sheet.

- *Handwriting Recognition*. The software had troubles recognizing the "/" in situations such as "N/A". This was a day 1 comment; later the team switched to "-" for N/A as it was converting NA to unrelated characters such as "43." FRAs had to write out *square feet* and *feet* since the system did not accept SF or FT.

- The components were not numbered keyed for the three test buildings as it was done for the training building.

- The FRAs occasionally found several of the blocks too small to write in some of the information.

- Towards the end of day during task five, on two of the survey days, FRAs ran out of sheets to record data for Tab 8 due to an issue with adding more rows to print within Microsoft Excel that was encountered by Adapx Inc.

- The data downloading was challenging as the software package being used was still under development. Capturx for Microsoft Excel is not to be released until October 2008. It displayed most of the digital ink but not all of it, and even less was converted to text in cells. It would commonly convert 10 to 20 rows of data and then skip a large number of rows and convert another 10 to 20 rows. Apparently the amount of data collected each day on each pen overloaded the software during the download process as the digital ink from the pen can be quite memory intensive.

- The use of single value attributes meant multiple entries for each component, which was very repetitive.

- The collection of installation data on every component was difficult, as most of the information was not available on the components, such as doors and windows.

<u>Productivity Related Issues.</u>

- The biggest productivity challenge was having to write out the attributes each time, particularly the attribute names. The team attempted to overcome this by using short abbreviations for the attribute names, and then utilizing the find and replace tool in Microsoft Excel when they performed the data entry/correction in the office.

Observer Reflections

- The technology is very useful in collecting data for Tabs 4, (Space) 7, (Component) and 14 (Installation) but it is very challenging for collecting attributes. It may be possible to improve the attribute collection process with this technology by changing the attributes that are collected and possibly developing a form to collect the data needed that could be easily cut and pasted into the COBIE spreadsheet.

- It would be possible to utilize this technology to operate as a single individual for collecting data. However, the loss of quality control without a second person reviewing the collected data would be a negative for a single person team.

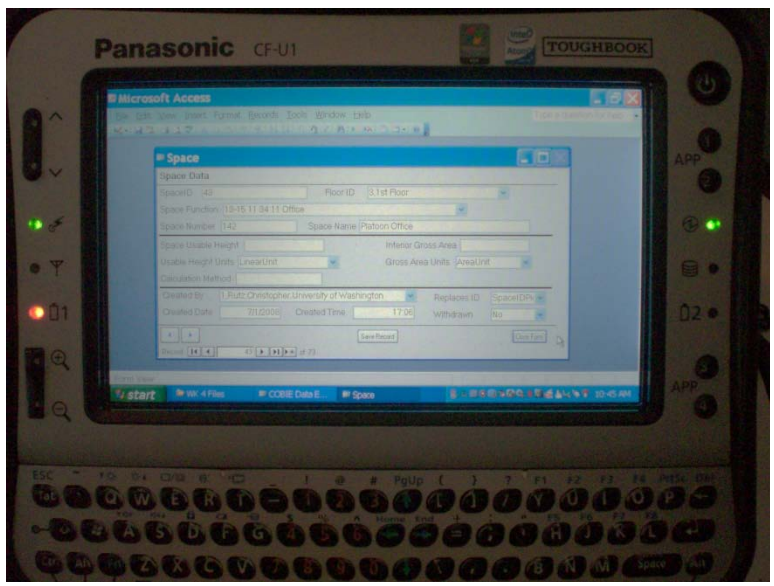
- It appeared that as the week progressed, the team got comfortable with the technology and in the process their attention to detail began to waver. This could be due to the repetitiveness of the tasks and components (i.e. doors).

Field Study – Week Four

Introduction

The fourth week of field trials ran from 4 August 2008 to 8 August 2008 utilizing the standard schedule in Figure 1. The technology and methodology utilized this week was a Microsoft Access database used on a Panasonic Toughbook U1 ultra-mobile computer. The Microsoft Access database was the same database used in week two of these trials with the exception of forms or user interface (UI) which were restricted to better fit on the wide-screen format of the Toughbook U1 screen. The Toughbook U1 is a new system recently released by Panasonic that features:

- New Intel Atom Z250 processor able to power Windows XP or Windows Vista
- 5.6” WSVGA sunlight viewable LED touch-screen
- 1GB of memory
- Solid state drive
- QWERTY keyboard
- Wi-Fi, USB, SD card slot
- Hot-swappable twin batteries with up to 9 hours of battery life
- Magnesium alloy chassis with a sealed all weather rugged design



The Microsoft Access database was structured from the COBIE spreadsheet with tables for Tabs 4 (Space), 7 (Component), 8 (Attributes) and 14 (Installation). The user interface consisted of a menu with a button to select each of the four tabs. A form would then open for that specific tab in which the user could enter the appropriate data using the form. The image to the right shows the space form open on the Toughbook U1 that was utilized by the FRAs during this week.

Description of Work Processes

The original work plan was for the field survey team to only use Microsoft Access and the attribute references on paper. During the first task at the training building, the team developed their work process, which differed from the original work plan. First, they asked if they could use Microsoft Excel to record all of the attributes in order to make use of the cut and paste functions because the attributes were a very repetitive process. The team was shown how to export the tables from the database so that the Excel file would be properly built for easy input to the database at the end of the day. They also found the right click with the pen interface to be challenging, which was overcome by the use of a standard USB mouse attached to the Toughbook U1. The team decided that one member would go around the space and collect the necessary data utilizing the attribute reference sheets that were pre-printed. The FRA would write a component name at the top of the attribute sheet and any installation data that was available. They would then complete the attribute form and return it to the other FRA. It would then be input into the database or the Excel file. They found this easier than having one person reading the information while the other tried to enter it in the appropriate areas. The FRA operating the Toughbook U1 would find a place to set up and stay there while the other FRA would walk around the space collecting the necessary data on paper.

The team generally would do spatial data for the space first. Occasionally, they would collect all the spatial data for all the spaces first, and then collect the other data as they changed spaces. The team also exported the tables for Tabs 4, 7 and 14 to Microsoft Excel in order to quickly reference pre-loaded data, as the database was not sorting data in the correct order using the forms. This approach may have been chosen because the primary FRA operating the Toughbook U1 was extremely comfortable using Microsoft Excel.

Issues Encountered

<u>Logistics and Site Issues.</u>

- *Access issues with Building 9137.* Escort was late which delayed the start of task 2 and did not return after lunch, thus extending the length of task 4 by five minutes.

- *Incorrect or lack of data plates on components.* In general, data plates on doors were painted over and impossible to get information from even in some of the newer buildings that were surveyed.

- *Room access.* Day Four (Building 11751), room 208 (SIPRNET Room) was secured and unable to be opened. It was not completed as in the previous weeks.

- *Unscheduled power outage.* Day Four (Building 1751), the power went out about mid-morning due to a major power failure across Fort Lewis. The power failure did not have any major effect on the survey as most of the spaces received direct or indirect sunlight, which allowed the survey team to continue working.

<u>Technology/COBIE Issues.</u>

- Mouse functionality with the pen was challenging. In particular the right click function was difficult to use.

- The keyboard was challenging if one tried to hold it and type with both hands.

- The Toughbook U1 was difficult to hold with one hand throughout the day.

- The use of single value attributes meant multiple entries for each component, which was very repetitive.

- The collection of installation data on every component was difficult as most of it was not available on items such as doors and windows.

<u>Productivity Related Issues.</u>

- *Ineffficiency and repetitiveness of entering attribute data.* One of the larger productivity issues was the collection of attributes and having to re-enter the attribute name every time for every line on the attribute reference sheets. This team attempted to overcome this by using Microsoft Excel to utilize the cut and paste functions, which the right click function on the Toughbook U1 made difficult. The small size of the keyboard also did not help accomplish these tasks any faster.

- *Access pick-list issues.* The sorting of records in Microsoft Access was random making locating pre-loaded records challenging. The team overcame this issue by exporting all the tables to Microsoft Excel so they could quickly reference data there and then type in the identification number in the database to bring up the correct record to enter data. However, this meant a lot of switching between windows while performing just one task.

Observer Reflections

- The general work process utilizing paper collection and Access input was very similar to that of Week 2.

- The FRA who was the primary data collector was very vigilant with his attention to detail over the course of the week. However, he began to overlook components that needed to be captured towards the end of the week.

- It would be possible to utilize this technology to operate as a single individual for collecting data. However, the loss of the quality control without a second person reviewing the data collected would be a negative for a single person team.

- The choice to use Microsoft Excel was driven by one FRA who was very comfortable with this application. The FRA seemed to be over-thinking the process and was consistently trying to improve the process by changing how data input was performed. He may have been more comfortable with the COBIE spreadsheet than with the database.

- Similar to the FRAs' paper and data entry (Week 1) processes, the use of Microsoft Excel greatly improved the speed of input for attributes over the Acer team's strict use of the Access forms.

Data Analysis

Task 3.2 involved conducting a comparative analysis of the alternative technologies used in the Field Test. Qualitative data were collected regarding the FRAs experiences with the technologies. Productivity data were collected based on the work performed each day. Workload comparison data were collected each week based on a survey completed by the FRAs using factors developed by NASA. Cost data were developed based on equipment cost and productivity observed.

Qualitative Comparison

Each of the FRAs was asked to evaluate the four technologies used for data collection on Friday afternoon after they had had an opportunity to work with all four. They were each given the same set of questions to answer. Their responses are shown in Tables 1, 2, and 3.

Table 1. Initial Reaction to the Technology.

Paper	Acer Laptop	Adapx Digital Pen	Panasonic U1
Simple and easy to use but with considerable data entry time	Easy to work with and very efficient for data collection	Easy and simple to use	Efficient for data collection
Twice the work, increased probability of errors in transcribing	Likes the ability to input data while partner was collecting attribute data	Very interesting, but concerned about handwriting recognition in data entry	Lighter than the tablet PC, but the screen is too small
Slow but tested approach	Ideal because there is no paper to carry and very little post processing	Able to pre-load words and touch to copy to a field	Lightweight but no handwriting capability
Recorder must have readable handwriting	Non-mobile. Requires two people to accomplish survey	Still requires carrying many sheets of paper	PC lacks mouse capability

Table 2. Anticipated Benefits to Use.

Paper	Acer Laptop	Adapx Digital Pen	Panasonic U1
Can move quickly throughout the field because you do not have to worry about handwriting recognition	Data entry is smoother. One person collects data, and the other enters the data	Data entry is faster, but need a handwritten back-up in case technology fails	Lighter weight than tablet PC

Quicker to write than type Can use abbreviations and short hand notation	Large screen with icons Everything is done and formatted in the field	Elimination of hand keystroke entry Have both a paper and electronic copy	Best ergonomic design No post processing of data entry

Table 3. Anticipated Challenges to Use.

Paper	Acer Laptop	Adapx Digital Pen	Panasonic U1
Many sheets of paper to manage	Heavy to carry around for an extended period of time	Must be precise with handwriting recognition	Small screen is difficult to use and typing takes longer with thumb keyboard
No direct data entry	Short battery life	Lack of an erase function on pen if an error is made	No handwriting input feature
Interpreting the written data	Ergonomics of setting up is uncomfortable – need a chair	Time spent correcting data pen recorded incorrectly	

Productivity Analysis

Productivity was analyzed by reviewing the number of records a survey team completed for a task (e.g., one complete row in the COBIE spreadsheet) within the allotted time for the task (see Appendix A: COBIE Survey Productivity Tables). The productivity rates for data collection and data entry were considered separately and labeled as shown in Table 4.

Table 4. Data Collection and Entry Analysis Codes.

Identifier	Description
Week1A – Paper_Collect	Paper & Data Entry – Data Collection
Week1B – Paper_Input	Paper & Data Entry – Data Entry
Week2A – Acer_Collect	Acer Laptop – Data Collection
Week2B – Acer_Input	Acer Laptop – Data Entry
Week3A – Adapx_Collect	Adapx Digital Pen – Data Collection
Week3B – Adapx_Input	Adapx Digital Pen – Data Entry
Week4A – U1_Collect	Panasonic U1 – Data Collection
Week4B – U1_Input	Panasonic U1 – Data Entry

<u>Productivity Assumptions</u>

- Each completed COBIE record was given equal consideration, regardless of whether it was spatial, component, installation, or attribute data.

- The time to upload the information from the Adapx digital pens was not recorded in the observation times, due to challenges of the beta software. Considering the fully developed Capturx for Excel would upload all data from the pens in a single batch, a factor of 40 rows per minute (one row per 1.5 seconds) was factored into the Adapx productivity rates.

- The Access program used by the Acer team was not fully developed. Pick-lists and other automated features of the forms were not functioning properly, which approximately tripled the active data entry time. To compensate for the technological malfunction, the Raw Rows Entered for Acer Data Entry has been multiplied by a factor of three.

- Data collection for the Paper (Week 1) and Adapx (Week 3) teams required searching the preloaded component or entering a new component for every Installation, so the team was credited "Rows collected/identified" for at least the number of Installation IDs they collected.

- Data entry for the Acer laptop (Week 2) and Panasonic U1 (Week 4) teams required searching the preloaded component or entering a new component for every Installation, so the team was credited "Rows collected/identified" for at least the number of Installation IDs they collected.

- Data collection for the Paper (Week 1) and Adapx (Week 3) teams only had to input or verify their handwritten notes during data entry, so they did not receive any data entry credit for preloaded information (e.g. they received raw data entry scores).

<u>Productivity Rates</u>

For each technology trial, the two-person survey team divided responsibilities differently. For the team working with paper forms (Week 1), the surveyors collected data in the field and entered data in the office as a team. The Adapx Digital Pen team also had two people collecting data (each using a different digital pen), but only one person would upload the data and perform quality control at the end of the day, due to logistical issues (Capturx for Excel still in beta version and only available in the Seattle Adapx office). For the Acer laptop and Panasonic U1 teams, one person collected data, while the other person was completely immersed in the technology, trying to keep pace with the rate at which the data collector was providing information. The number of personnel per task for each technology is summarized in Table 5.

Table 5. COBIE Technologies - Personnel per Task.

Task	Paper Forms	Acer Laptop	Adapx Digital Pen	Panasonic U1
Data Collection	2-psn	1-psn	2-psn	1-psn
Data Entry	2-psn	1-psn	1-psn	1-psn

The total number of completed records was divided by the task time, to yield the "Raw Rows per Minute." The "Raw Rows per Minute" was divided by the number of personnel performing the task to yield the productivity rate of a single person, entitled "Rows/Min/Psn."

Total number of completed records / Time = Raw Rows per Minute

Raw Rows per Min / Number of personnel for task = Rows/Min/Psn

Productivity Comparison Analysis

Data collection and data entry productivity rates were compared within and across the teams. A team's average productivity rates were used in the cost computations. Table 6 provides short descriptions of the tasks per building. It is important to note that, for "Tues-Bldg 9137," the tasks labeled "Pod" 1, 2, and 3 indicate the teams' starting point for their time task, but that all the "pods" (quad of three-bedroom suites) included common areas, bedrooms, and external hallway.

Table 6. Survey Task Legend

Tues Bldg 9137	**Task #1 Egress Space**	**Task #2 Pod 1: Common Area**	**Task #3 Pod 2: Bedroom**	**Task #4 Pod 3: Hallway**	**Task #5 Mechanical Space**
Wed Bldg 3218	**Task #1: Dayroom**	**Task #2 Egress Space**	**Task #3 Corridor w/ Bathrooms**	**Task #4 Mechanical Space**	**Task #5 Corridor w/ Office**
Thurs Bldg 11751	**Task #1 Mechanical Space**	**Task #2 Egress Space**	**Task #3 Multi-function Space**	**Task #4 Corridor w/ Bathroooms**	**Task #5 Corridor w/ Offices**

Productivity per Technology

The teams productivity rates generally improved from day to day and as they progressed to the next task during each day, with the highest productivity usually occurring during the task before lunch. When the surveyors returned from lunch, productivity fell in most cases, but then began to climb again for the last task. In some cases, a team performed worse than the previous day, possibly due to human factors (e.g., fatigue, physical comfort) or alteration of operational procedures. Figures 1 through 8 display the data collection and data entry productivity rates as the teams progressed throughout the week.

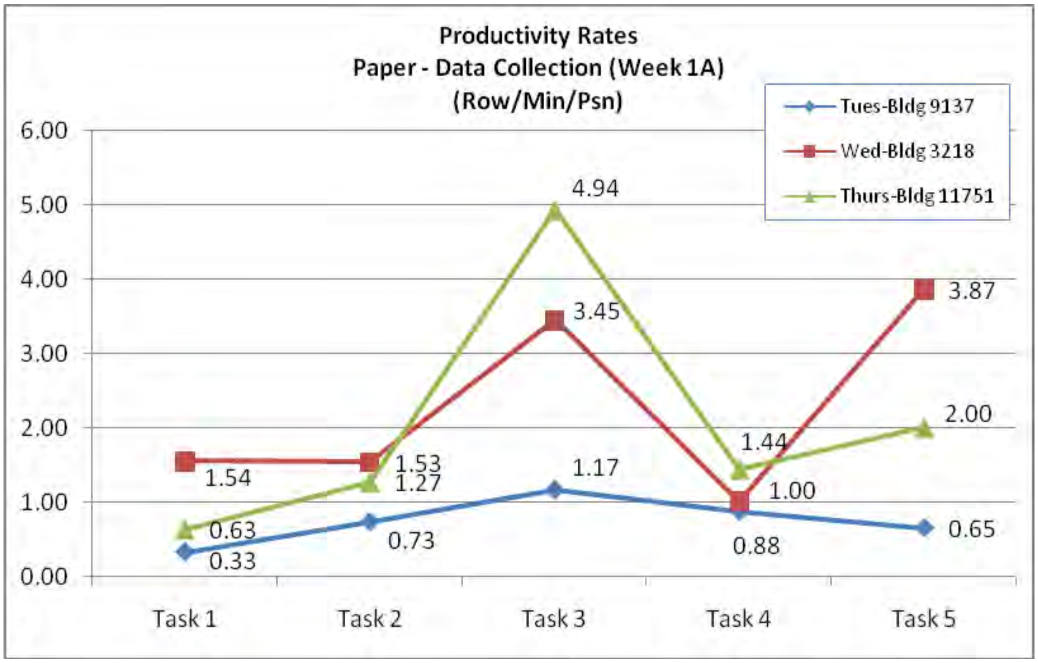


Figure 1. Paper Forms Data Collection Productivity Rates.

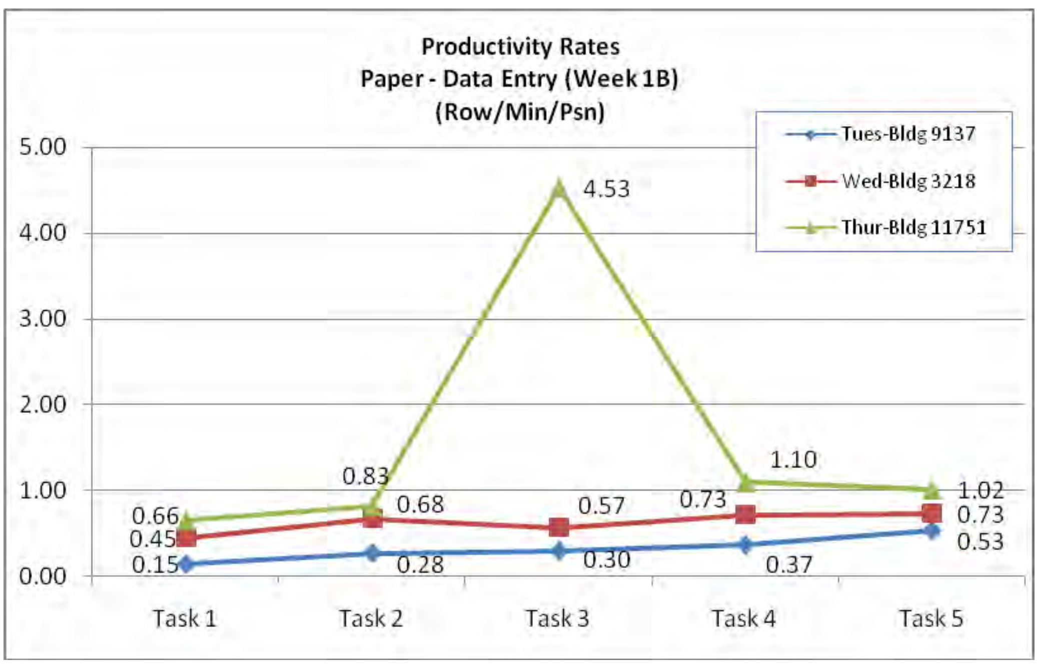


Figure 2. Paper Forms Data Entry Productivity Rates.

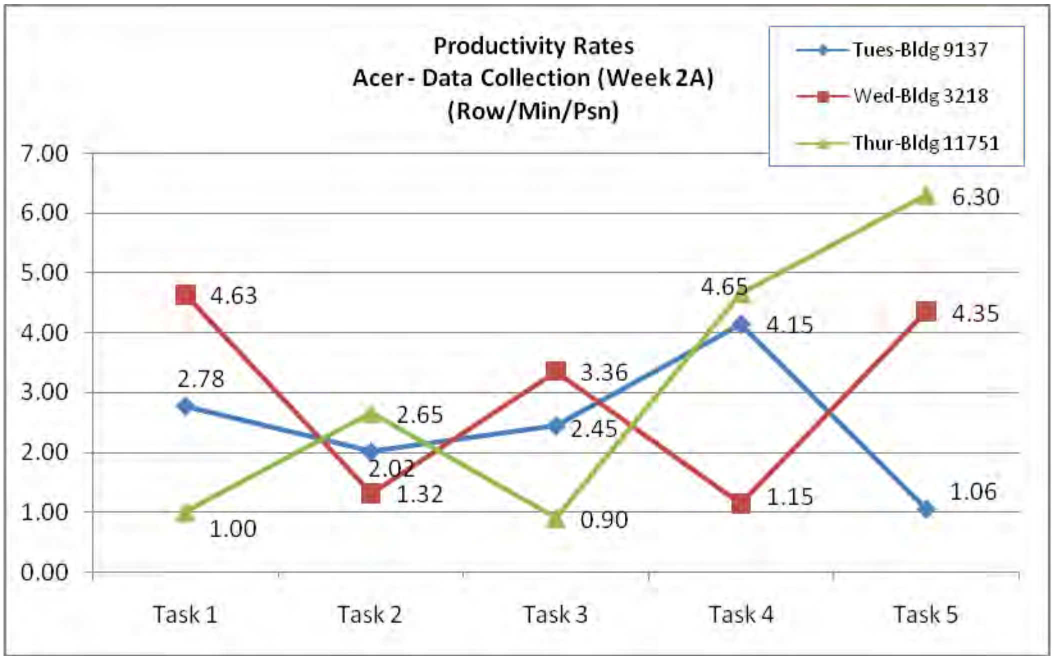


Figure 3. Acer Laptop Data Collection Productivity Rates.

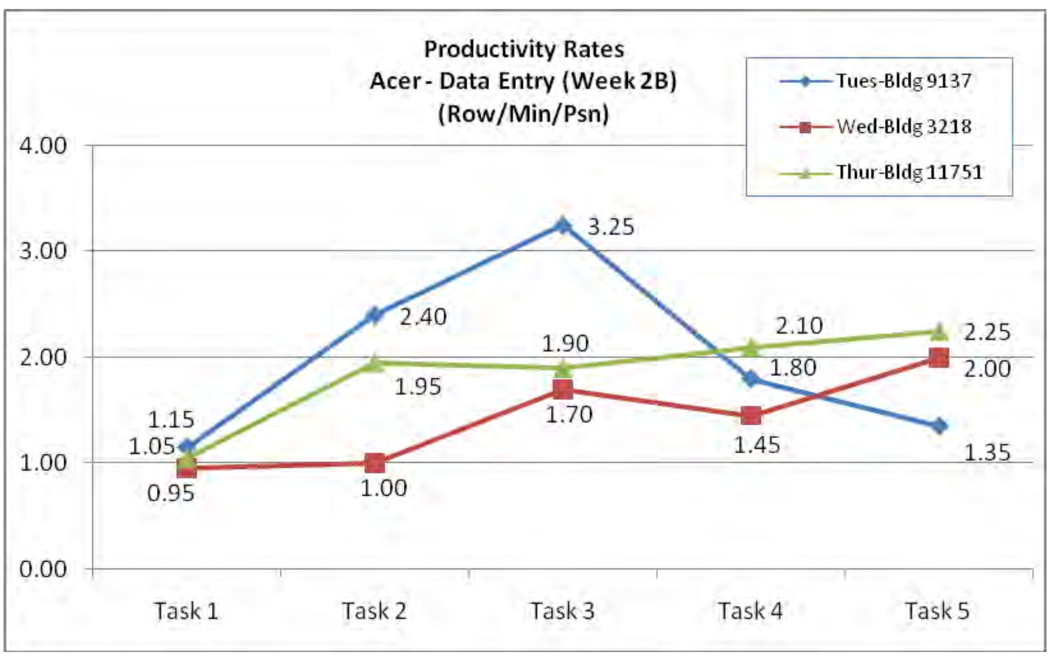


Figure 4. Acer Laptop Data Entry Productivity Rates.

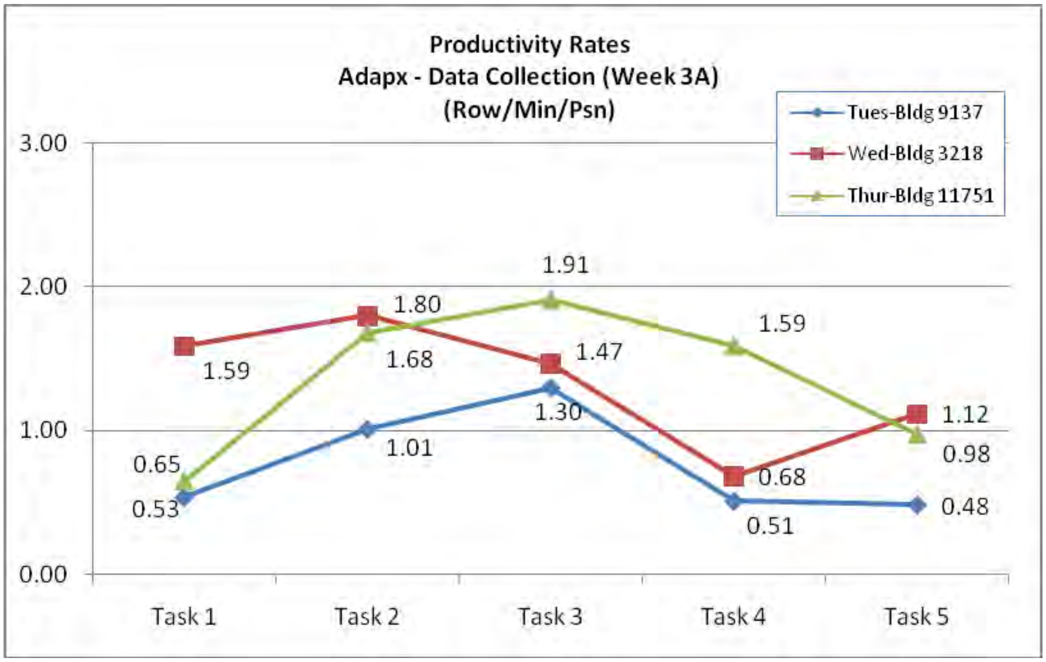


Figure 5. Adapx Digital Pen Data Collection Productivity Rates.

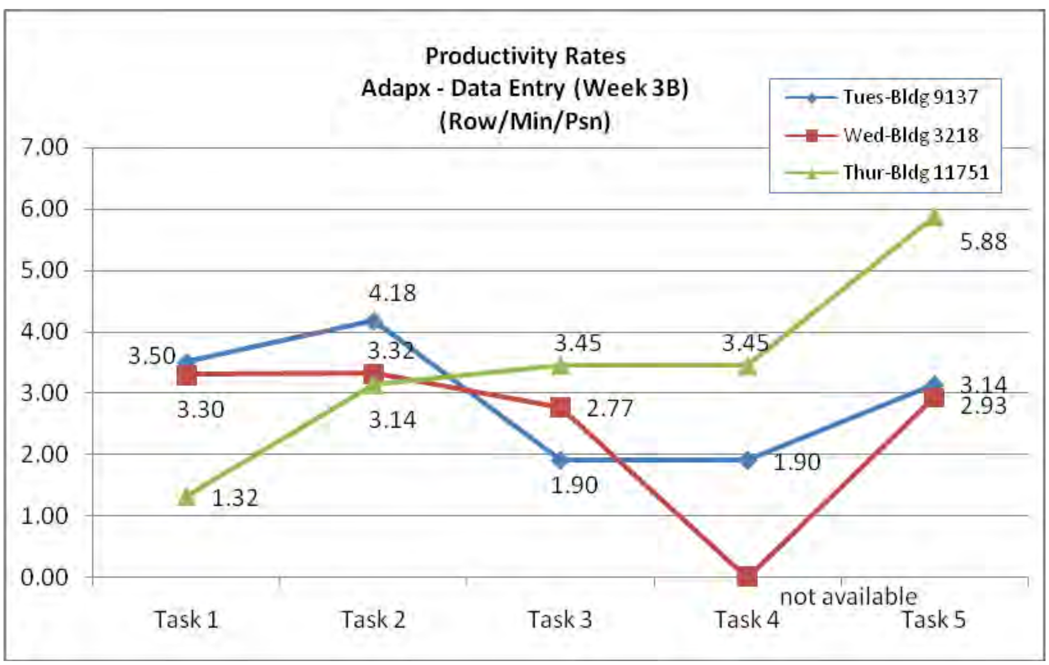


Figure 6. Adapx Digital Pen Data Entry Productivity Rates.

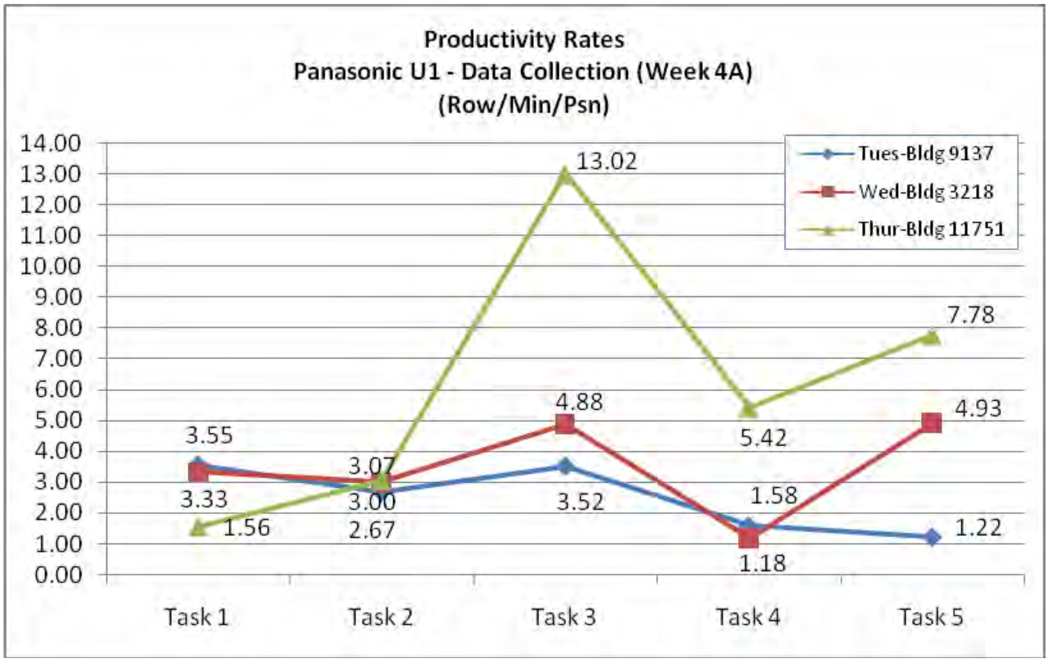


Figure 7. Panasonic U1 Data Collection Productivity Rates.

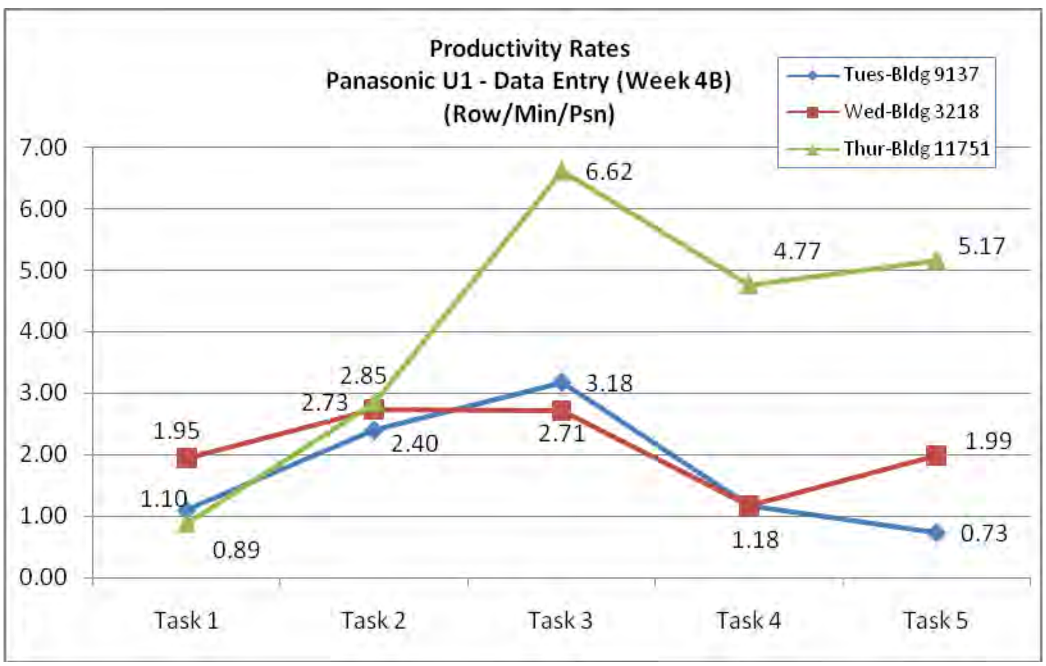


Figure 8. Panasonic U1 Data Entry Productivity Rates.

Productivity Improvement

Figures 9 through 16 depict how the teams' productivity rates changed as they continued their tasks for each day. The team's data collection and data entry productivity rates for Task 1, at the start of each day, were used as the basis of comparison for the remaining four tasks.

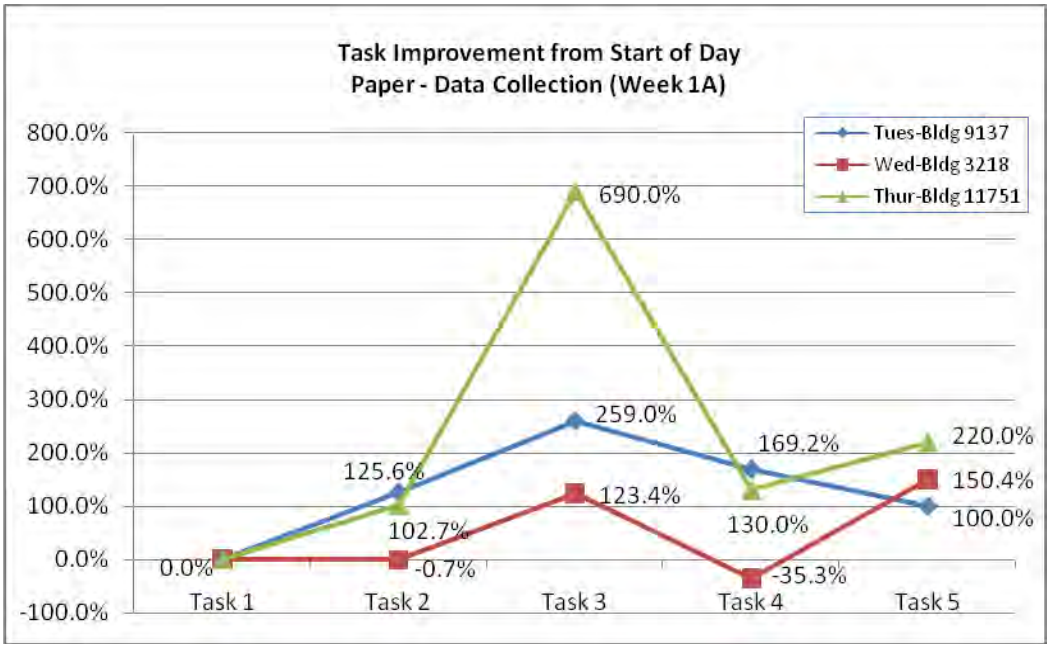


Figure 9. Paper Forms Data Collection - Improvement Rates.

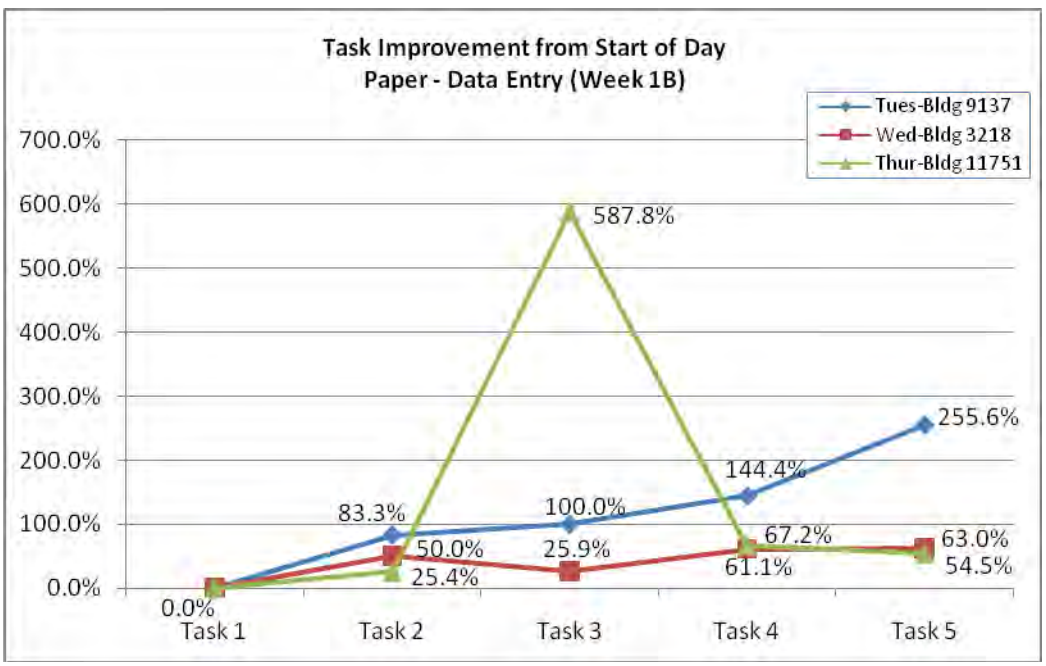


Figure 10. Paper Forms Data Entry Improvement Rates.

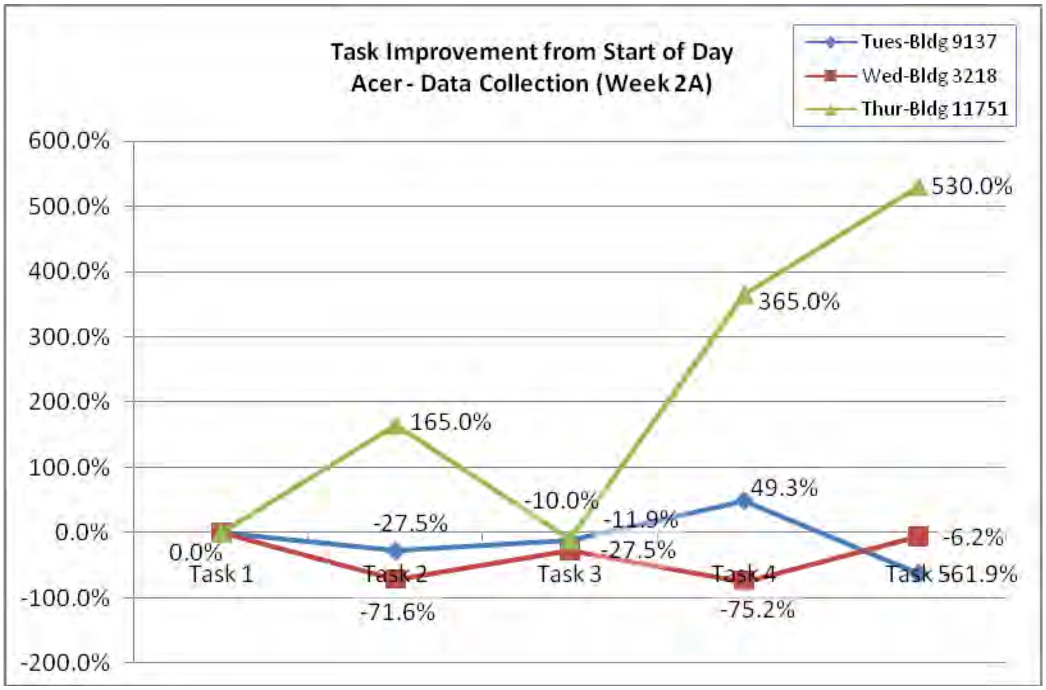


Figure 11. Acer Laptop Data Collection - Improvement Rates.

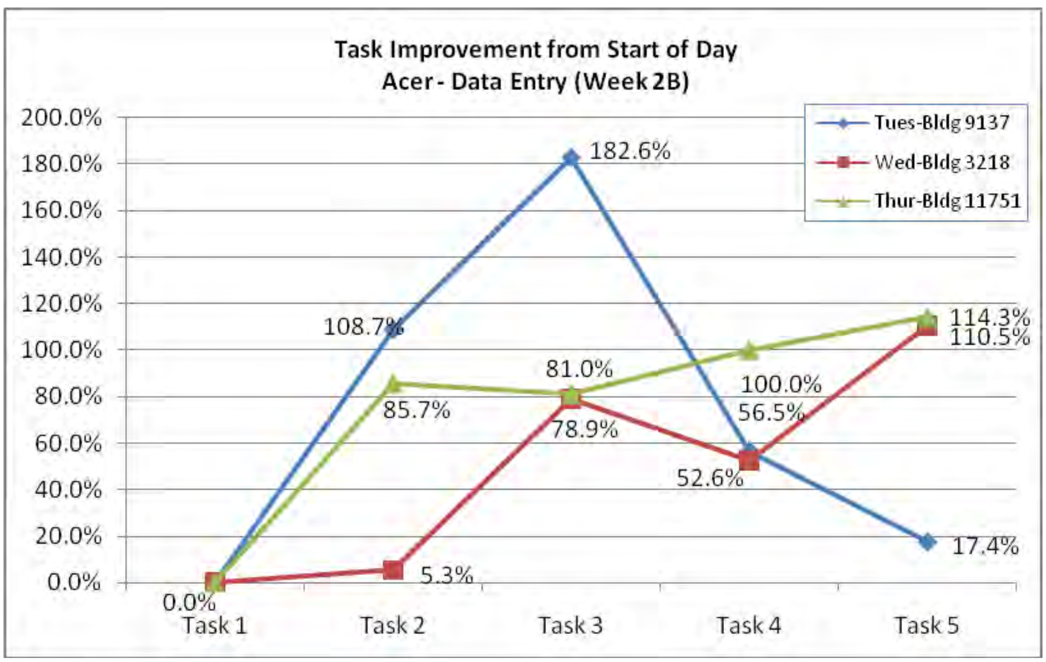


Figure 12. Acer Laptop Data Entry - Improvement Rates.

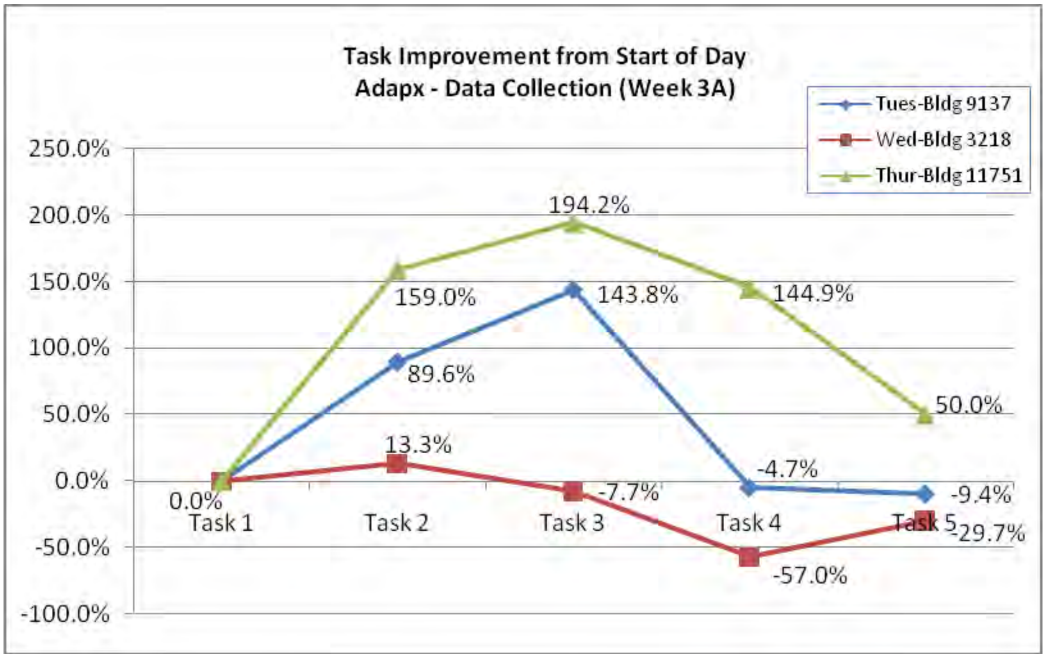


Figure 13. Adapx Digital Pen Data Collection - Improvement Rates.

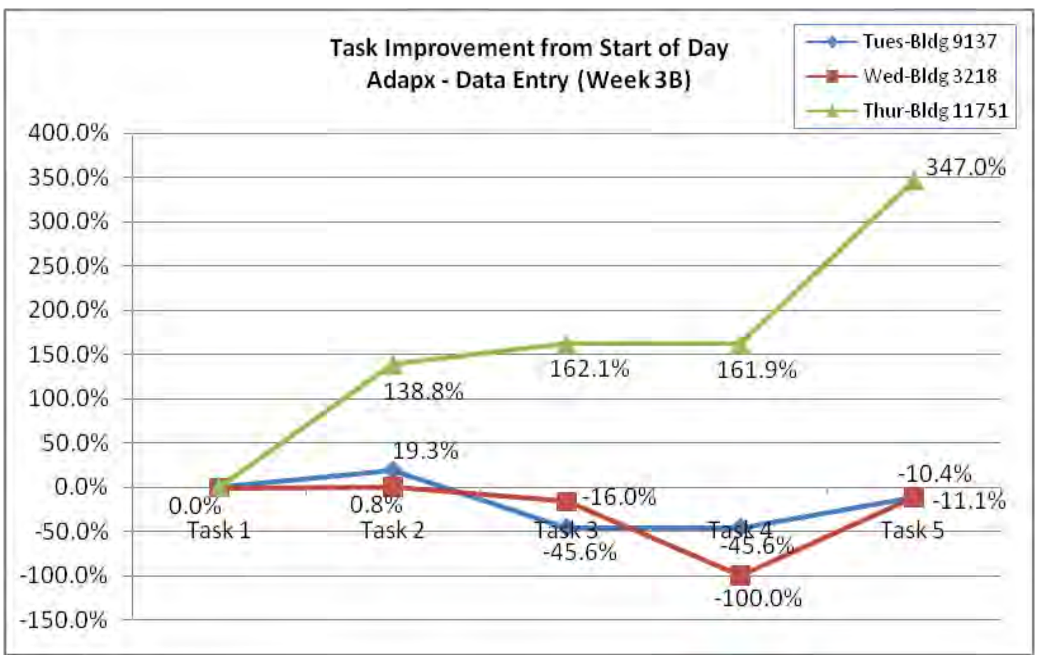


Figure 14. Adapx Digital Pen Data Entry - Improvement Rates.

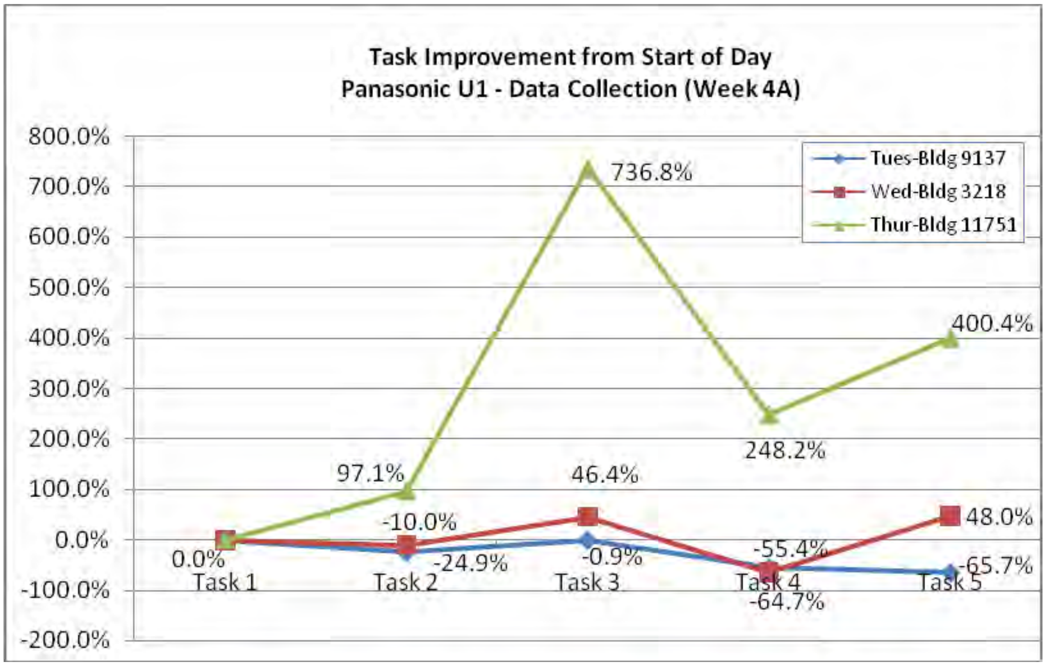


Figure 15. Panasonic U1 Data Collection - Improvement Rates.

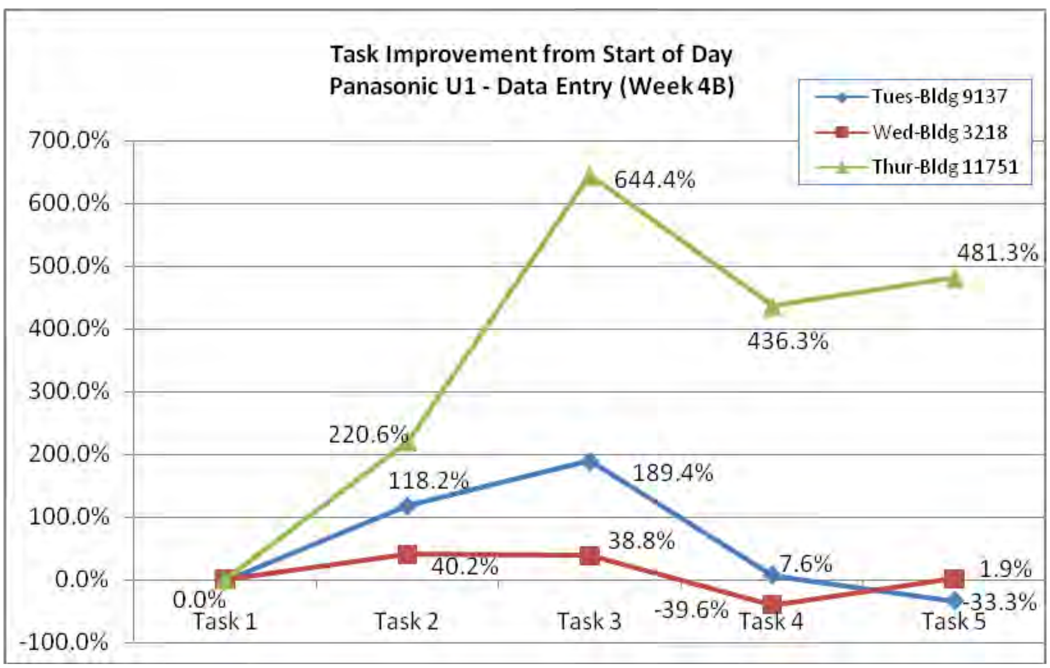


Figure 16. Panasonic U1 Data Entry - Improvement Rates.

Productivity Rates per Task Type

The teams' productivity rates were also affected by the functional area that they were surveying. Figures 17 through 20 display the data collection and data entry productivity rates when mechanical, egress, and general occupied spaces were surveyed. In general, teams were able to survey occupied spaces at faster rates than other functional spaces.

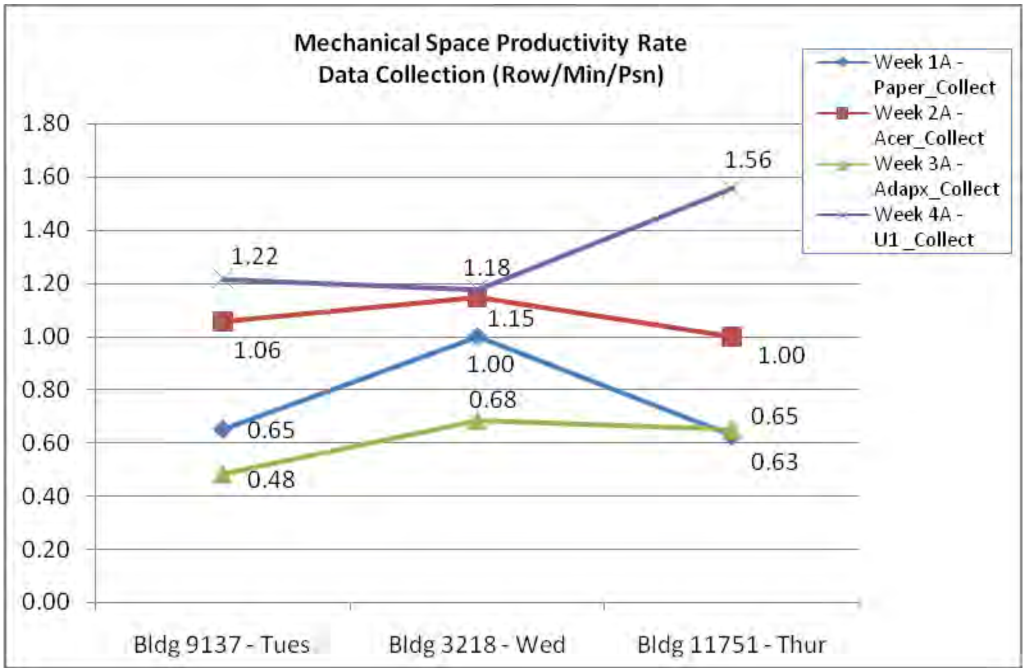


Figure 17. Mechanical Spaces – Data Collection Productivity Rates.

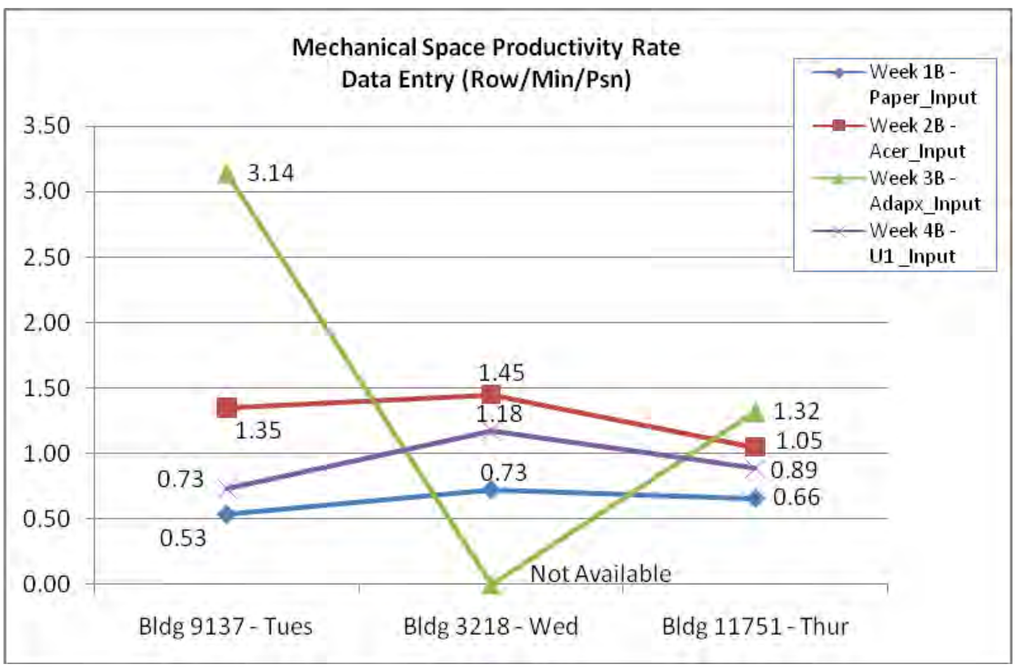


Figure 18. Mechanical Spaces – Data Entry Productivity Rates.

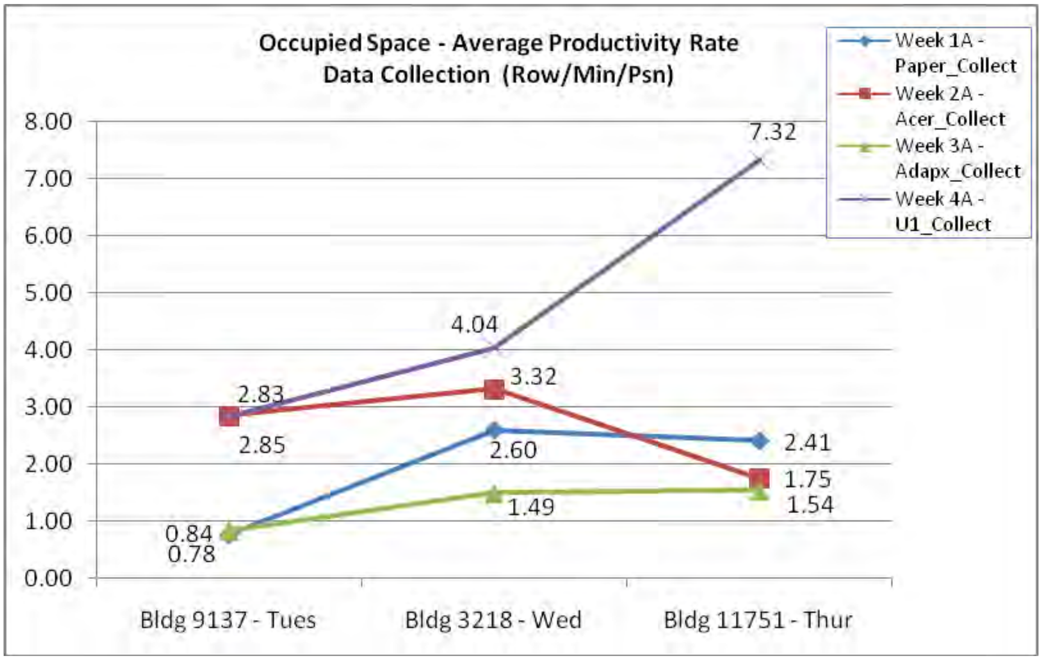


Figure 19. Occupied Spaces – Data Collection Productivity Rates.

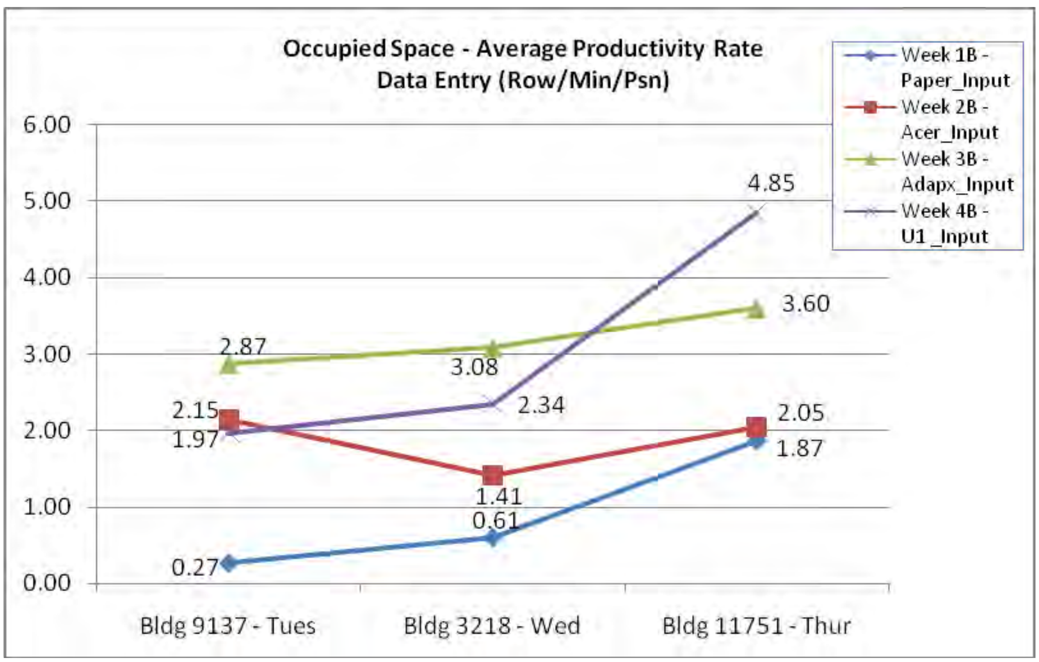


Figure 20. Occupied Spaces – Data Entry Productivity Rates.

Monthly and Yearly Output Estimates

Each team's monthly and yearly outputs of how many average facilities they could survey in one month and in one year were estimated using the following relationships.

- *"Average Building" Characteristics.* A hypothetical "Average Building" has characteristics from averaging measurable values of buildings 9137, 3218, and 11751. This includes averages of the physical area (square footage), records per square foot (Rows/SF) or per building, and estimated preparation time for a survey.

- *Survey Preparation Time - "Preparation Subtotal".* The time invested in preparing the buildings for field tests were limited to specific areas in the building. These times were multiplied by a factor, yielding the estimated time required to prepare for the entire facility (See Appendix B: COBIE Survey Preparation Activities).

- *Estimated Records per Square Foot of a Building or Mechanical Space– "Rows/SF".* Each team's sum of collected records (not records fully entered in the COBIE spreadsheets) was divided by the collected square footage to yield the average number of records per square foot in a building, "Rows/SF."

  Sum of collected records / Collected sq ft = Rows/SF

- *Estimated Total Records per Building or Mechanical Space – "Est Total Rows/Bldg" and "Est Total Rows/Mech".* The estimated records per square foot of a building were averaged across the four survey teams and multiplied with the total square footage of occupied space to yield an estimated quantity of total records for the building. A similar approach was followed to yield an estimated quantity of total records for the mechanical spaces.

  (Average of Rows/SF) * (Total Sq Ft of Bldg) = Est records per Building

  (Average of Rows/SF) * (Mech Space Sq Ft) = Est records per Mech Space

- *Average Productivity Rates - Rows/Min/Psn.* A team's average productivity rate for data collection and data entry, over the three days of actual survey, were used to compute the estimated time to accomplish a full building survey. Average productivity rates were distinguished between occupied spaces and mechanical spaces. Occupied spaces included offices, bedrooms, common areas, multi-purpose areas, storage (bays and closets), and egress areas. Mechanical spaces included mechanical, electrical, and communication rooms.

- *Operational Man-hours to Complete a COBIE Survey for Occupied Spaces "Est Mnhrs to Survey Occupied Space".* The average productivity rates for data collection and data entry (Rows/Min/Psn) were divided into the estimated total records for the building (Est Total Rows/Bldg), yielding the total minutes the team would invest in surveying all occupied spaces in a building. This number was divided by 60 minutes/hr to yield the "Est Mnhrs to Survey Occupied Space".

- *Operational Man-hours to Survey Mechanical Space "Est Mnhrs to Survey Mech Space".* The average mechanical space productivity rates for data collection and data entry (Rows/Min/Psn) were divided into the estimated total records for the space (Est Total Rows/Mech), yielding the total minutes the team would invest in surveying all the mechanical spaces. This number was divided by 60 minutes/hr to yield the "Est Mnhrs to Survey Mech Space".

- *Total Estimated Operational Man-hours to Complete a COBIE Building Survey***.** The operational man-hours to complete a COBIE survey for occupied spaces was added to the operational man-hours to complete the survey for the mechanical spaces, to yield the "Total Est Operational Mnhrs per Bldg".

  Est Operational Mnhrs per Bldg + Preparation Subtotal
  = Total Mnhrs per Bldg

- *Available Man-hours per Month.* Assumes the two-person survey team has 6 hours (12 man-hours) of fully productive work each day, and that there are 20 workdays per month (accounting for travel time, rest breaks, weekdays/holidays).

  2-person team * 6-hr survey per day * 20 workdays per month
  = 240 Mnhrs/month

- *Estimated Monthly and Annual COBIE Outputs (Figure 21).* The total estimated operational man-hours to complete a COBIE survey was added to the survey preparation time for an "Average Building." These man-hours were divided into the number of monthly and annual man-hours available.

  240 Mnhrs/month / Avg Total Mnhrs per Bldg = Monthly Output

- *Optimal Targets for Monthly and Annual COBIE Outputs.* The most effective COBIE technology will still be limited by human and logistical factors. It is assumed that, realistically, three buildings can be surveyed every two weeks if a team performed optimally and faced minimal logistical issues. This equates to 6 buildings monthly and 75 buildings annually as optimal output.

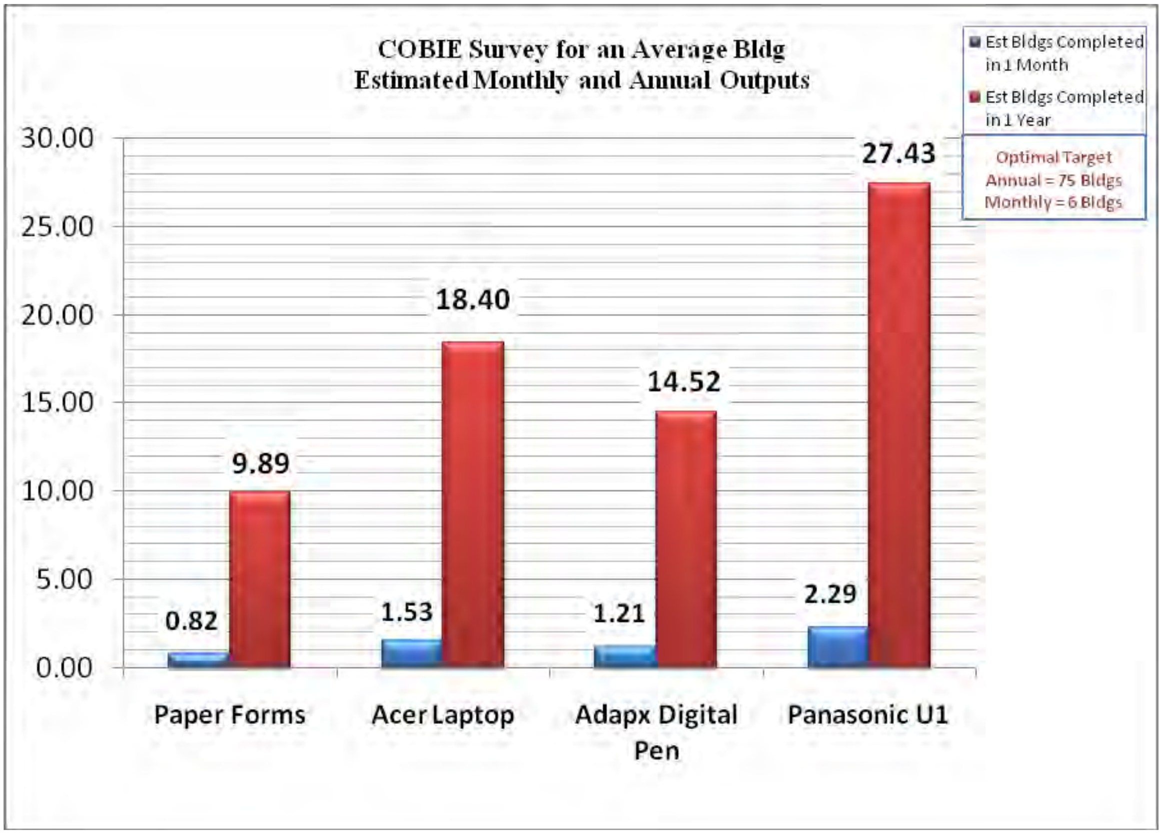


Figure 21. COBIE Technologies - Monthly and Yearly Ouputs.

Workload Analysis (NASA data)

To quantify the load on the research students for data capture and data entry, an analytical method known as the Task Load Index (NASA TLX Version 2.0) was used. This method was published by the NASA Ames Research Center in December 2003 (Entire report can be found at http://humansystems.arc.nasa.gov/groups/TLX). The NASA Task Load index is a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings for the factors shown in Table 7.

Table 7. Rating Scale Definitions (NASA TLX 2003).

Title	Endpoints	Descriptions
Mental demand	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical demand	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Effort	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Performance	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Frustration level	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Pre-study surveys and post-study surveys were collected to develop the relative weights for each workload subscale item. The average and standard deviation of the post assessment evaluations are shown in Table 8 through13.

Table 8. Effort Assessment.

Effort	Post-Assessment Value Average	Post Assessment Value Standard Deviation
Paper Data Entry	88	6
Panasonic U1Data Collection	59	4
Paper Data Collection	41	10
Panasonic U1Data Entry	30	5
Adapx Digital PenData Entry	12	5
Acer Laptop Data Entry	3	1
Adapx Digital Pen Data Collection	0	0
Acer Laptop Data Collection	0	0

Effort had the highest averages with relatively low standard deviations. Effort is the combined effort from mental and physical loads. There is a strong contrast between paper data entry at 88 with the Adapx digital pen and Acer laptop data collection at 0.

Table 9. Performance Assessment.

Performance	Post-Assessment Value Average	Post Assessment Value Standard Deviation
Adapx Digital Pen Data Collection	51	5
Panasonic U1 Data Entry	49	14
Panasonic U1 Data Collection	47	22
Adapx Digital Pen Data Entry	33	22
Paper Data Entry	29	5
Acer Laptop Data Entry	12	7
Acer Laptop Data Collection	8	2
Paper Data Collection	0	0

Performance loads were next with high values for Adapx digital pen data collection and entry as well as Panasonic U1 data collection and entry. Paper and Acer laptop data collection scores were low.

Table 10. Mental Demand Assessment.

Mental Demand	Post-Assessment Value Average	Post Assessment Value Standard Deviation
Paper Data Entry	48	6
Panasonic U1 Data Collection	40	4
Acer Laptop Data Collection	40	7
Acer Laptop Data Entry	29	29
Panasonic U1 Data Entry	23	7
Adapx Digital Pen Data Collection	17	5
Paper Data Collection	13	6
Adapx Digital Pen Data Entry	9	5

Mental demand, physical demand, temporal demand and frustration are all in the middle of the range. For mental demand, the highest demand tasks included paper data entry, Panasonic U1 data collection and Acer laptop collection, with Adapx digital pen data entry being the lowest demand.

Table 11. Frustration Assessment.

Frustration	Post-Assessment Value Average	Post Assessment Value Standard Deviation
Paper Data Collection	53	6
Acer Laptop Data Collection	39	1
Adapx Digital Pen Data Collection	34	6
Adapx Digital Pen Data Entry	24	26
Acer Laptop Data Entry	15	18
Panasonic U1 Data Entry	14	7
Paper Data Entry	13	11
Panasonic U1 Data Collection	8	18

For frustration, the paper data collect was rated highest – with the field researchers juggling 4 sets of spreadsheets, their equipment and other reference documents. The tasks with lower frustration levels included Panasonic U1 data entry, paper data entry, and Panasonic U1 data collection.

Table 12. Temporal Demand Assessment.

Temporal Demand	Post-Assessment Value Average	Post Assessment Value Standard Deviation
Adapx Digital PenData Collection	35	8
Paper Data Entry	27	6
Acer Laptop Data Collection	25	6
Panasonic U1 Data Collection	24	3
Acer Laptop Data Entry	21	18
Adapx Digital Pen Data Entry	19	10
Panasonic U1 Data Entry	9	4
Paper Data Collection	8	2

The temporal demand was higher for Adapx digital pen data collection and paper data entry than for Panasonic U1 data entry and paper data collection.

Table 13. Physical Demand Assessment.

Physical Demand	Post-Assessment Value Average	Post Assessment Value Standard Deviation
Acer Laptop Data Collection	18	8
Paper Data Collection	16	4
Adapx Digital Pen Data Collection	8	3
Adapx Digital Pen Data Entry	7	3
Acer Laptop Data Entry	0	0
Paper Data Entry	0	0
Panasonic U1 Data Collection	0	0
Panasonic U1 Data Entry	0	0

The physical demand was rated higher for data collection than it was for the data entry for the Acer laptop, paper, and Adepx digital pen; while there no differences in the ratings for the Panasonic U1. In general, temporal demand and physical demand did not have high values as compared to the other categories.

Comparing each of the eight tasks, with the six subscale items, we see that the load varies across the tasks as shown in Table 14.

Table 14. Comparison of Data Collected with Technology Used.

	Paper Data Collection / Entry	Acer Laptop Data Collection / Entry	Adapx Data Collection / Entry	Panasonic U1 Data Collection / Entry
Effort	41 / 88	0 / 3	0 / 12	59 / 30
Performance	0 / 29	8 / 12	51 / 33	47 / 49
Mental Demand	13 / 48	40 / 29	17 / 9	40 / 23
Frustration	53 / 13	39 / 15	34 / 24	8 / 14
Temporal Demand	8 / 27	25 / 21	35 / 19	24 / 9
Physical Demand	16 / 0	18 / 0	8 / 7	0 / 0

For paper data collection, frustration is the highest value at 53, with effort being second at 41. For paper data entry, effort was the highest at 88, with mental demand being second 48. For the Adapx digital pen, the performance load factor of 51 was the highest rating for data collection and 33 for data entry, and frustration and temporal demands coming in second in the thirties for data collection. For the Acer laptop, the mental demand 40 and the frustration 39 seem to be the main load issues for data collection, while the highest issue for data entry was mental demand at 29. The Panasonic U1 data show effort 59, performance 47, and mental demand 40 as having higher values than the Acer laptop, while data entry has a highest value of 49 for performance. For paper and the Panasonic U1, effort was ranked as the most important issue. Performance was highest for the Adapx digital pen, while it was second for the Panasonic U1. Frustration was high for paper and the Acer laptop, while temporal demands were a concern for the Adapx digital pen. Mental demand was also an issue for the Acer laptop and the Panasonic U1.

Economic Analysis

The economic analysis of employing the various technologies/methodologies for COBIE data collection considered fixed and operational costs. Equipment replacement, pay rates, and other related assumptions are listed in Table 15.

Table 15. COBIE Cost Factors and Assumptions.

	Description	Assumption
Equipment Costs		
Disposable survey items	Pens/pencils	6-month replacement
	Clipboards	
Office technologies	Desktop computer	3-year replacement
	Flat screen monitor	
	Laser printer	
Survey accessories	Measuring devices	3-year replacement
	Calculator	
	Mobile furniture: table, chair, wheeled cart	
COBIE technologies	Acer tablet laptop	3-year replacement
	Adapx Digital Pen	
	Panasonic U1	
Software Licenses	MS Windows Office 2007	Enterprise licenses available for all DPW procured technologies
	AutoCad 2004 or later	
Operational Costs		
COBIE Surveyors	Conducted by mid-level GS or WG equivalent personnel	$20/hour rate
COBIE Attribute Data Sheets	8.5” x 11” black and white prints	Used/required for all technologies
Adapx Digital Pen	11” x 17” color prints for all COBIE spreadsheets	Capturx technology creates an overlay matrix of microdots, which are the only truly blank-inked print. Any other print on the page that appears black is actually an infusion of multiple colors.

Equipment Cost Factors

Common survey equipment and technology-specific recommendations were considered in implementing the COBIE technologies. It is notable that mobile equipment items are among the recommended survey equipment items, as the physical comfort of the surveyors played an important role in the teams’ attitudes and performances during the study. Repetitive tasks, such as bending to write or putting down and picking up survey equipment, was fatiguing for personnel collecting data. Similarly, personnel who were assigned duties of data entry while in the field, using the Acer laptop and the Panasonic U1, were also physically taxed when the area did not have minimal furniture for their needs (i.e., table and chair).

The equipment costs to implement the various COBIE technologies for an average building was derived from averaging the equipment requirement estimates of Buildings 9137, 3218, and 11751. Average productivity rates of each team were used to determine the amount of expendable supplies each technology required monthly and annually. A detailed list of equipment recommendation and costs, per technology, are listed in Appendix C: COBIE Technology Equipment Costs.

Operational Cost Computations

Operational costs of implementing the COBIE technologies considered the ***overall average*** productivity rates for data collection and data entry, estimated preparation time to conduct a survey (limited to six buildings per month or 75 buildings per year), estimates of total records per building and mechanical space, and estimates of total man-hours required to complete the surveys. The operational costs to implement the various COBIE technologies for an average building are summarized in Figures 22 and 23, using information from actual field surveys of Building 9137, 3218, and 11751. Detailed tables of the operation costs are listed in Appendix D: COBIE Technology Operational Costs. An hourly rate of $20 was used in computing operational costs. Possible grades/steps of general schedule and wage grade employees are noted in Appendix E: Assumed Grade/Step for Hired Surveyors and Specialists (2008 Pay Schedules).

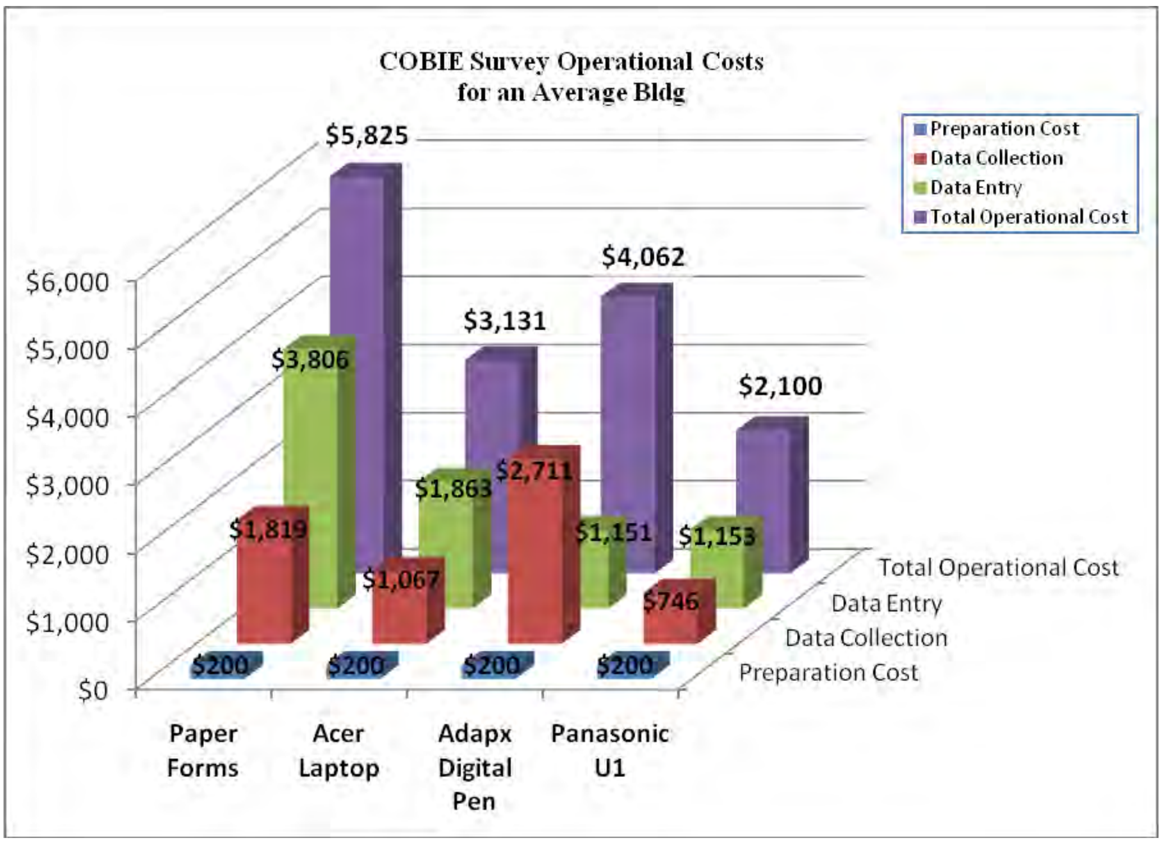


Figure 22. COBIE Survey Operational Costs for an Average Building.

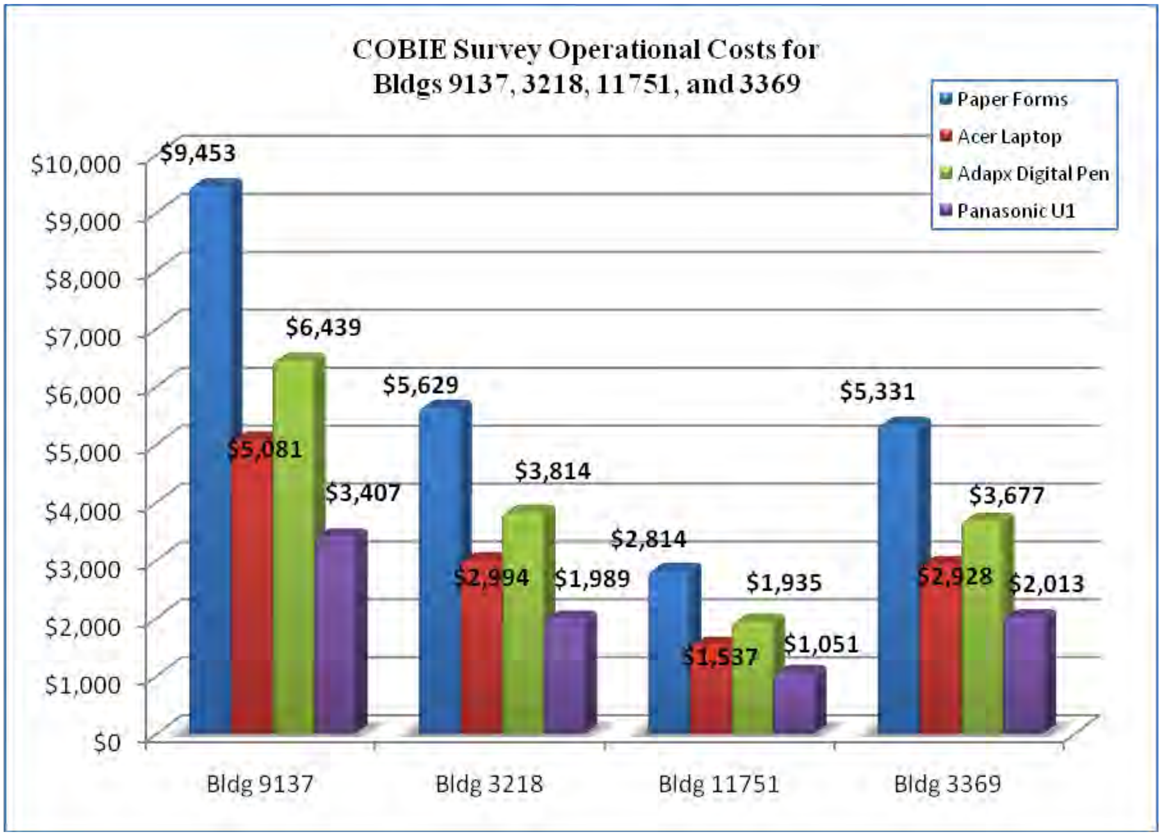


Figure 23. COBIE Survey Estimated Operational Costs per Building.

<u>Implementation Costs of COBIE Technologies</u>

The costs to implement the various COBIE technologies for an average building are summarized in Tables 16 and 17 using information from actual field surveys of Buildings 9137, 3218, and 11751, by adding equipment and operational costs. Separate cost tables for these buildings can be found in Appendix F: COBIE Cost Tables.

Table 16. Average COBIE Implementation Cost per Building.

Average Bldg	Est Equipment Costs per Bldg		Operational Costs per Average Bldg			TOTAL
	Common Data Collection Tools	Survey Technology Requirements	Preparation Cost	Data Collection	Data Entry	
Paper Forms	$30.78	$74.91	$200	$1,819	$3,806	**$5,931**
Acer Laptop	$16.54	$42.35	$200	$1,067	$1,863	**$3,190**
Adapx Digital Pen	$20.97	$10.28	$200	$2,711	$1,057	**$3,999**
Panasonic U1	$11.09	$22.81	$200	$746	$1,153	**$2,134**

Table 17. Average COBIE Implementation Monthly and Annual Costs.

Average Bldg	Average Equipment Cost per Bldg	Average Operational Cost per Bldg	Average TOTAL Cost per Bldg	Est Bldgs Completed in 1 Month	Monthly COBIE Survey Costs	Est Bldgs Completed in 1 Year	Annual COBIE Survey Costs
Paper Forms	$105.68	$5,825	$5,931	0.82	$4,887	9.9	$58,645
Acer Laptop	$58.89	$3,131	$3,190	1.53	$4,890	18.4	$58,684
Adapx Digital Pen	$440.39	$3,968	$4,409	1.21	$5,333	14.5	$63,993
Panasonic U1	$22.81	$2,100	$2,122	2.29	$4,852	27.4	$58,226

Spatial Information and COBIE

Information acquired through COBIE surveys can be enhanced by linking the data to 2D detailed information about a building's components and spatial configuration. The BIM can improve communications and efficiency in short/long-range planning, design, and daily facility operations planning.

- *Facility Exterior & Mechanical Space – 3D Model and Overlain Photo.* A skeleton model of the facility exterior and critical elements of the mechanical space are extruded from "point clouds" obtained through laser scans. Photographs are overlain onto the point clouds and model, all of which are represented and navigable in 3D.

- *2D Drawings.* 2D drawings of facility floor plans, electrical/communication access points, reflective ceiling plans, and heights (door, ceiling, sill) are useful for a variety of purposes by project planners, occupants, and facility maintenance personnel. For example, drawings can be keyed to a COBIE database or manufacturer links and referenced for maintenance service calls. The visual layout of the space clarifies which specific component needs attention, and the COBIE database or hyperlinks would streamline response procedures by making component specifications readily accessible.

- *Interior Photographs.* Some 2D drafting contractors offer a service to take photographs and key the images in the 2D drawings. This is a more economical method of portraying a 3D space, rather than performing 3D scans of each interior space.

Technological Services

It is not uncommon for operational demands or design standards to undergo several changes over the lifetime of a facility, leading to subsequent renovations. Paper and/or electronic drawings that reflect a facility's constructed design, known are "as-built" drawings, are filed and maintained at the Computer-Aided Design (CAD) office within the DPW. As-built drawings may be inaccurate for any number of reasons, such as a breakdown in construction close-out procedures or simply the lack of adequate CAD resources. Older buildings may only have paper copies of as-builts which, unless a full facility renovation was accomplished and new as-builts were provided to the CAD office, are not easily updated.

Improving the reliability and accessibility of this spatial information is an undertaking that requires dedicated resources and specialized skills. The UW team arranged a two-day conference from 9-10 July, where contractors were invited to demonstrate technologies and services that were either relevant to the COBIE study or in capturing 2D or 3D spatial geometries. The schedule of activities, which also included briefings to kick-off the 14 July – 8 August COBIE field studies, is shown in Table 18. A contact sheet of the vendors and contractors who contributed to information in this section is located in Appendix G: COBIE, 2D, and 3D Technology Services/Vendors.

Table 18. Technology Demonstration Schedule, 9-10 July 2008.

Fort Lewis - COBIE Field Test Brief & 2D/3D Advanced Technology Demonstrations

Wednesday, July 09, 2008		Duration
8:30	CERL Briefing - About COBIE and MAXIMO	0:45
9:15	UW Briefing - Research Goals, Summer Field Work	0:30
9:45	UW Briefing - Technologies for COBIE; Technologies for Advanced Data Sets	0:30
10:30	Adapx Hands-on Demonstration, Excel Application Development (Conference Rm)	1:00
13:00	2D Floorplans Drawing Services Demonstration (Bldg 2012, Select office areas)	0:45
14:00	David Evans & Associates LIDAR Demonstration (Location: Bldg 2012, Mech Rm)	0:45

Thursday, July 10, 2008		Duration
9:15	UW Brief - Recap of technologies for COBIE and Advanced Data Sets	0:15
9:30	2D Floorplan Services Presentation	0:30
10:00	LIDAR and TruView Presentation by David Evans and Associates	1:00

Adapx Digital Pen for Drawing Mark-Ups

In addition to briefing the features of Capturx for Excel, which was being released in beta version for inclusion in the COBIE field studies, Adapx provided a hands-on demonstration of Capturx for Autodesk Design Review. This program enables personnel to make notes or sketches on paper copies of as-built drawings, citing differing building conditions, which can then be uploaded directly into an Autodesk DWF file. The Adapx pen strokes are saved as a separate layer of digitized ink on the electronic as-built drawing. DPW CAD personnel can open the DWF file in AutoCAD and update as-built drawings accordingly. Regardless of whether the drawings are updated immediately or postponed to a future date, the valuable information from the mark-ups can be easily shared and accessed through the DWF free viewer.

2D Drawings for Accurate Floor Plans

2D as-built floor plans can be collected with various technologies and input into a CAD file. 2D Floorplan Services gave a technology demonstration in July 2008 that demonstrated the processes that they use to create as-built floor plans with very tight tolerances. They use a Bluetooth-enabled laser-measuring device to upload the measurements directly into drafting software operating on a table computer. The file is then e-mailed to the drafting department for finishing before it is ready for the client.

The report, including a compact disc with the files, is then prepared and given to the client.

Through professional contract services, such as 2D Floorplans, who presented at the July technology demonstration, CAD as-built drawings can be created, verified, and/or updated to reflect existing conditions. Creating drawings is a skill that requires experience in both surveying and computer drafting. To accurately portray the geometrical layout of a facility, 2D Floorplans utilizes a Leica Disto laser-measuring tool, with Bluetooth technology, to directly input the measurements from the Disto meter to a pen-tablet computer. Using a proprietary drafting software, known as PlanSurvey, and following systematic measuring and "closing" methods, the company produces high-quality CAD drawings within ± ¼" accuracy.

2D Floorplan Featured Technologies

- *Leica Disto Laser Distance Meter.* This laser-measuring tool is equipped with Bluetooth to enable direct data transfer to various programs, to include Microsoft Excel/Word and AutoCAD. The Disto meter is also programmed with useful arithmetic functions, such subtracting/adding measurements or computing areas.

- *Pen-tablet Computer.* 2D Floorplans used the Fujitsu Lifebook series, such as the Fujitsu P1620, which weighs slightly over two pounds and is touch-responsive and Bluetooth enabled. Full specifications are listed in Appendix H: Survey Equipment Listing.

- *PlanSurvey and Leica fieldPro.* Plug-in applications to Autodesk products that provide special menus and toolbars, specifically designed to aid personnel in creating real-time drawings on-site (e.g., common wall-types and facility components). Leica Disto meter readings can be directly inputted when drafting wall lines.

2D Floorplan Deliverables (Examples are shown in Appendix I: 2D Floorplan Sample Plans)

- Available products, non-inclusive: Floor plans, electrical communication layout, heights, reflective ceiling plan, furniture plan, color-coded occupant/leasing plan, interior/exterior/keyed photographs.

- Paper prints available in any drawing size standard.

- Electronic CAD files.

Considerations for Self-Performed 2D Renderings

- Creating drawings requires the properly trained personnel with the correct tools and regular field practice. Methodologies must also be employed to minimize accumulated errors when measuring the interior spaces of a whole building, since wall junctions are seldom true 90-degree corners and sections are not perfectly straight.

- A basic level of building construction is also useful, so the surveyor may account for wall thicknesses and identify infrastructure components/areas that would be useful to facility users and project planners.

- The measurements and/or sketches of the surveyor should be converted to a CAD drawing to enable future access and usage of the information, which also requires a skilled computer draft technician.

- 2D Floorplan personnel undergo five days of training, usually conducted by the software developer (e.g., Leica) and complete approximately six months of field work to become proficient.

- Benefits

  - Experienced staff to create range of 2D drawings

    - Floor plans (including all permanent equipment locations)

    - Reflective ceiling

    - Electrical/communication outlets

    - Wall/window/door heights

  - Laser measuring devices with direct input to tablet PCs

  - Accuracy validation methods

- Limitations

  - Manual analysis of CAD files can provide certain COBIE information, but additional field surveyors required to capture all essential fields

  - May require contractor escorts on installation

3D Scanning and Modeling

Light Detection and Ranging (LIDAR) is a technology that utilizes lasers to determine the distance to an object or surface. The prevalent method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves instead of light, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. The current high-definition LIDAR systems for fast, 360° survey with near photo realistic imaging. The most popular systems are typically Leica HDS laser scanning technology. David Evans and Associates demonstrated their LIDAR system by scanning the sub-basement mechanical space and the rear elevation of building 2012 in July 2008. The team took approximately seven scans of the sub basement mechanical space and three scans of the rear elevation, which took approximately two hours. The following day David Evans and Associates presented the data set that was collected demonstrating how one could easily get dimensional information from the data set. They also demonstrated how the data set could be manipulated to show certain elements.

Leica ScanStation 2 and HDS6000 Laser Scanners

Through survey contractors, such as David Evans and Associates (DEA), highly accurate 3D renderings of a facility can be achieved. DEA has owned and operated High-Definition Surveying systems (laser scanning) since 2001. Their Leica HDS technology allows the collection, visualization, and modeling of complex structures and sites with remarkable speed. The Leica 3D laser scanner employs pulsed laser technology to scan target areas and return "point clouds", which looks like a detailed color rendering of a scene, in a matter of minutes. Experienced DEA technicians ensure the accuracy and completeness of several scans that are "interstitched" into a three dimensional system of point clouds, which can be viewed from any perspective. High-resolution photographs are overlain on the point clouds and viewable through a Leica freeware, known as TruView. Coordinates may be acquired from the photograph, since every point has an accurate horizontal and vertical position.

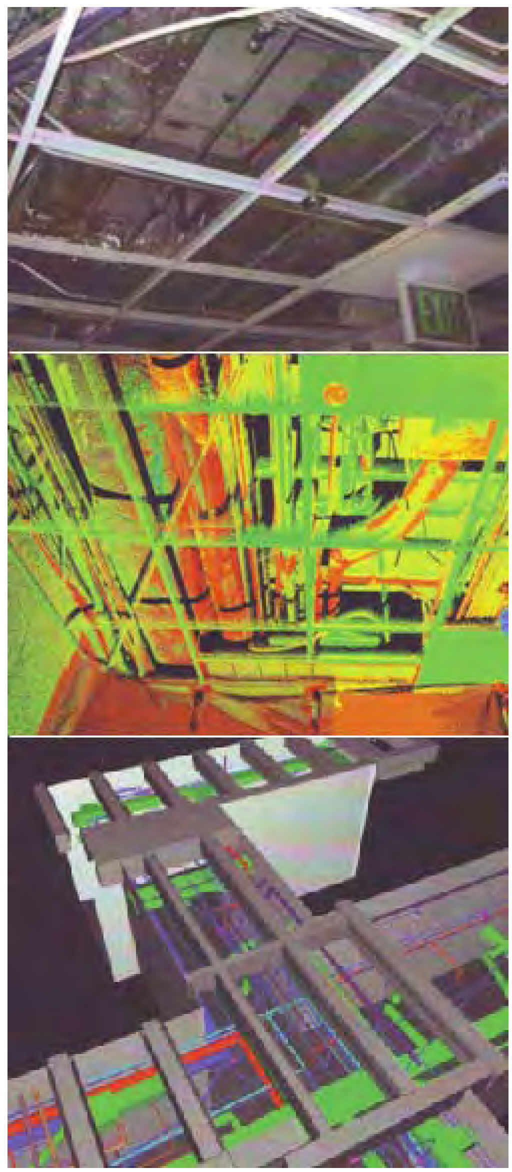
Leica HDS Scan - Point Clouds

The scanned point clouds can be further developed into three-dimensional CAD models with software programs that greatly facilitate the creation of geometric shapes. Three-dimensional modeling is relatively expensive, costing anywhere from 2-8 times that of scanned and interstitched point clouds, depending on the complexity and level of detail of the model. For this reason, only critical facility features and infrastructure elements should be modeled.

3D Scanning and Photo Technologies

Leica TP S800

- Leica high-speed laser scanners emit a pulsed laser that measures tens of thousands of points per second.
    - Leica ScanStation 2
    - Leica HDS6000 Scanner
    - Total Stations, such as the Leica TP S800, establishes a control network for the exterior scanning and references the scan to global position coordinates.



Photo, Point Clouds, and 3D Model of Ceiling Space

- Camera mounts, such as the 0-360 Panoramic Optic™ is a specially designed lens attachment, with an exclusive optical reflector, which captures an entire 360 degree panorama with a single shot.
- Digital cameras, such as the Canon Powershot G9 and A650 IS, can produce 12.1 megapixel photos that are overlain on point clouds.

Point Cloud and 3D Modeling Software

- Cyclone is a family of software for point cloud processing. The software enables interstitching of multiple scans and includes automatic recognition and extraction of point clouds to CAD geometries.
- Cloudworx is a family of software that enables users to work with large point clouds, directly using AutoCAD tools and commands to create 2D drawings and 3D models.
- Leica Cyclone PUBLISHER publishes point cloud data for web-based sharing and viewing allowing access from anywhere in the world. Using the FREE Leica TruView panoramic point cloud

viewer, users can view, zoom in, or pan over point clouds naturally and intuitively.

3D Scanning Deliverables

- Electronic file of point clouds with panoramic photograph overlay, viewable via TruView freeware
- Scalable level of modeling: 2D plans/elevation, 3D skeleton or detailed models

Considerations for Self-Performed 3D Scanning and Modeling

- 3D scanning requires a high initial investment in hardware and maintenance, as well as at least one year continuous training/practice to reach an adequate level of accuracy and proficiency with the equipment and software. Unless there is a high volume of facilities to be scanned by personnel dedicated to scanning and point cloud processing, it is not economical to self-perform HDS surveys.
- Since Fort Lewis has a high volume of facilities that may be modeled, it would be advisable to hire a full-time resident 3D modeler to create skeleton models of building exteriors and critical elements within mechanical spaces, in accordance with IFC standards. A cost comparison of hiring a 3D modeler versus contracting the service is shown in Table 19 and in Appendix J: 2D and 3D Cost Calculations. Possible general schedule and wage grade levels for this position are noted in Appendix E: Assumed Grade/Step for Hired Surveyors and Specialists (2008 Pay Schedules).
- Benefits
    - Detailed and accurate representations for future reference
    - True coordinates of all data points for precise measurements
    - LIDAR and photogrammetry combination for realistic, scaled models.
- Limitations
    - Full facility model/photos requires scanning each room
    - COBIE data capturing to be accomplished separately
    - Extensive library of 3D models/photos may require separate server
    - May require contractor escorts on installation.

Table 19. Comparison of Contracted versus In-House 3D Modeling.

Building	3D Scanning/Modeling - Contract Service (Cost Ranges)								In-House 3D Modeler (Cost Ranges)			
	Scans		Scanning and TruView		Detailed 3D Model		Skeleton 3D Model		Est Working Days		Skeleton 3D Model	
	low	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*
Bldgs 9137	14	20	$7,500	$9,000	$33,000	$45,000	$15,000	$27,000	9	15	$2,813	$4,688
Bldgs 3218	12	18	$7,200	$8,000	$28,500	$40,000	$14,400	$24,000	8	14	$2,500	$4,375
Bldgs 11751	12	30	$7,000	$8,500	$33,000	$45,000	$14,000	$25,500	9	15	$2,813	$4,688
Bldgs 3369	22	27	$11,000	$14,000	$50,000	$68,000	$22,000	$42,000	10	16	$3,125	$5,000

COBIE and Spatial Data to a BIM

Development of a BIM would involve the integration of the COBIE data, 2D floor plans, and 3D model discussed in this report. The creation of the 3D model should be coordinated with the COBIE survey, so that naming conventions are standardized to enable automation of linking data between COBIE and the IFC-standard skeleton model. It is recommended that a BIM technician be hired to integrate the 2D, 3D, and COBIE information. Provided the BIM technician is knowledgeable of COBIE and IFC standards, it is also assumed he/she will be able to complete one building in a period of one to two weeks.

Estimated cost ranges for developing BIMs are shown in Figures 24 through 28, which considers a mix of contracted services and in-house personnel (hired staff). Costs for acquiring 2D floor plans via contract services are shown for Buildings 9137, 3218, 11751, and 3369 to provide a concept of cost ranges. In reality, only Building 3218 requires the 2D floor plan services because the facility has undergone extensive renovations in the past two decades that have not been properly documented. The BIM technician is estimated to have an annual salary of $50,000. Possible general schedule and wage grade levels for this position are noted in Appendix E: Assumed Grade/Step for Hired Surveyors and Specialists (2008 Pay Schedules).

Bldgs 9137

Occupied Space:	FY06 Barracks building, featuring quads of 3-bedroom suites with shared common area and numerous access/egress points				
Occupied Area:	33730.48 sq ft				
Mechanical Space:	Rectangular, densely equipped space				
Mechanical Area:	607.52 sq ft				
Floors:	3				
Rooms:	380				
External Dimensions (W-L-H):	55.25	217.45	34.45	feet	

2D Floorplans - Contract Service	Cost Range low	Cost Range high
Interior Floorplan	$2,474	$3,148
Elec Receptacle Plan	$1,125	$1,462
Interior Heights	$787	$1,125
Reflective Ceiling	$1,799	$2,811
Subtotal	$6,185	$8,546

3D Scanning - Contract Service		Cost Range low	Cost Range high
Exterior Fascade	Scanning and TruView	$4,500	$5,000
Mechanical Space	Scanning and TruView	$3,000	$4,000
	Subtotal	$7,500	$9,000

3D Modeling - In-House*		Cost Range low	Cost Range high
Exterior Fascade	Skeleton 3D Model	$1,250	$1,250
Mechanical Space	Skeleton 3D Model	$2,500	$2,500
	Subtotal	$3,750	$3,750

COBIE Survey and Integration - In-House**		Cost Range low	Cost Range high
COBIE Survey	Panasonic U1	$3,097	$3,785
COBIE/Model Integr	BIM Technician	$1,042	$2,083
	Subtotal	$4,138	$5,868
	Total (Cost Range)	**$21,573**	**$27,164**

*Assumes full-time in-house 3D modelerer for creation of skeleton model

** Assumes full-time in-house BIM technician for integration of COBIE and spatial data

Figure 24. COBIE to BIM Estimated Cost - Building 9137.

Bldgs 3218				
Occupied Space:	FY67 Multi-use bldg w/offices on first floor, two floors of dorm rooms above, basement storage, and annexed offices			
Occupied Area:	39618.45 sq ft			
Mechanical Space:	Rectangular, open space; sparsely equipped			
Mechanical Area:	800.65 sq ft			
Floors:	4			
Rooms:	132			
External Dimensions (W-L-H):	38.83	217.67	37.91	feet

2D Floorplans	Cost Range low	Cost Range high
Interior Floorplan	$2,977	$3,769
Elec Receptacle Plan	$1,392	$1,789
Interior Heights	$996	$1,392
Reflective Ceiling	$2,185	$3,373
Subtotal	$7,550	$10,324

3D Scanning - Contract Service		Cost Range low	Cost Range high
Exterior Fascade	Scanning and TruView	$4,500	$5,000
Mechanical Space	Scanning and TruView	$2,188	$2,188
	Subtotal	$6,688	$7,188

3D Modeling - In-House*		Cost Range low	Cost Range high
Exterior Fascade	Skeleton 3D Model	$1,250	$1,250
Mechanical Space	Skeleton 3D Model	$2,700	$3,000
	Subtotal	$3,950	$4,250

COBIE Survey and Integration - In-House**		Cost Range low	Cost Range high
COBIE Survey	Panasonic U1	$1,821	$2,225
COBIE/Model Integr	BIM Technician	$1,042	$2,083
	Subtotal	$2,862	$4,309

Total (Cost Range)	**$21,050**	**$26,070**

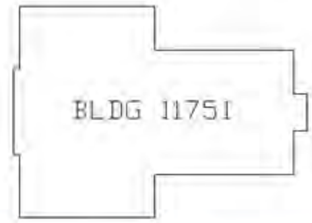
*Assumes full-time in-house 3D modelerer for creation of skeleton model

** Assumes full-time in-house BIM technician for integration of COBIE and spatial data

Figure 25. COBIE to BIM Estimated Cost - Building 3218.

Bldgs 11751

Occupied Space:	FY06 Company HQ with administrative spaces on first floor, large bathrooms/changing area, and large adjoining storage bay with a mezzanine
Occupied Area:	24004.78 sq ft
Mechanical Space:	Rectangular, densely equipped space
Mechanical Area:	456.62 sq ft
Floors:	2
Rooms:	70
External Dimensions (W-L-H):	121.23 | 165.52 | 28.00 | feet



2D Floorplans		Cost Range low	Cost Range high
Interior Floorplan		$1,740	$2,220
Elec Receptacle Plan		$780	$1,020
Interior Heights		$540	$780
Reflective Ceiling		$1,260	$1,980
	Subtotal	$4,321	$6,001

3D Scanning - Contract Service		Cost Range low	Cost Range high
Exterior Fascade	Scanning and TruView	$4,000	$4,500
Mechanical Space	Scanning and TruView	$3,000	$4,000
	Subtotal	$7,000	$8,500

3D Modeling - In-House*		Cost Range low	Cost Range high
Exterior Fascade	Skeleton 3D Model	$1,250	$1,250
Mechanical Space	Skeleton 3D Model	$2,500	$2,500
	Subtotal	$3,750	$3,750

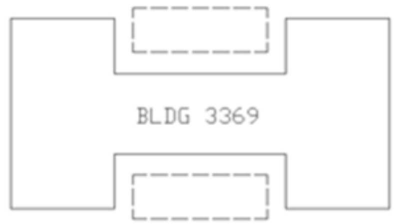
COBIE Survey and Integration - In-House**		Cost Range low	Cost Range high
COBIE Survey	Panasonic U1	$976	$1,193
COBIE/Model Integr	BIM Technician	$1,042	$2,083
	Subtotal	$2,018	$3,276
	Total (Cost Range)	**$17,088**	**$21,527**

*Assumes full-time in-house 3D modelerer for creation of skeleton model
** Assumes full-time in-house BIM technician for integration of COBIE and spatial data

Figure 26. COBIE to BIM Estimated Cost - Building 11751.

Bldgs 3369

Occupied Space:	FY06 Company HQ bldg with meeting spaces first floor, offices on second floor, and two large adjoining storage bays on either side of administrative			
Occupied Area:	39618.45 sq ft			
Mechanical Space:	Rectangular, densely equipped space			
Mechanical Area:	800.65 sq ft			
Floors:	2			
Rooms:	79			
External Dimensions (W-L-H):	137.42	273.58	28.00	feet



2D Floorplans	Cost Range low	Cost Range high
Interior Floorplan	$2,663	$3,250
Elec Receptacle Plan	$1,488	$1,781
Interior Heights	$1,194	$1,488
Reflective Ceiling	$2,075	$2,957
Subtotal	$7,419	$9,476

3D Scanning - Contract Service		Cost Range low	Cost Range high
Exterior Fascade	Scanning and TruView	$8,000	$10,000
Mechanical Space	Scanning and TruView	$3,000	$4,000
	Subtotal	$11,000	$14,000

3D Modeling - In-House*		Cost Range low	Cost Range high
Exterior Fascade	Skeleton 3D Model	$1,563	$1,563
Mechanical Space	Skeleton 3D Model	$2,500	$2,500
	Subtotal	$4,063	$4,063

COBIE Survey and Integration - In-House**		Cost Range low	Cost Range high
COBIE Survey	Panasonic U1	$1,842	$2,251
COBIE/Model Integr	BIM Technician	$1,042	$2,083
	Subtotal	$2,884	$4,335

Total (Cost Range)	**$25,365**	**$31,873**

*Assumes full-time in-house 3D modelerer for creation of skeleton model

** Assumes full-time in-house BIM technician for integration of COBIE and spatial data

Figure 27. COBIE to BIM Estimated Cost - Building 3369.

Estimated Average Bldg

Occupied Space:	Average building, based on Bldgs 9137, 3218, and 11751			
Occupied Area:	32451.24 sq ft			
Mechanical Space:	Rectangular, densely equipped space			
Mechanical Area:	621.59 sq ft			
Floors:	3.00			
Rooms:				
External Dimensions (W-L-H):	71.77	200.21	33.45	feet

Average Bldg

2D Floorplans		Cost Range low	Cost Range high
Interior Floorplan		$2,397	$3,046
Elec Receptacle Plan		$1,099	$1,424
Interior Heights		$775	$1,099
Reflective Ceiling		$1,748	$2,722
	Subtotal	$6,019	$8,290

3D Scanning - Contract Service		Cost Range low	Cost Range high
Exterior Fascade	Scanning and TruView	$4,333	$4,833
Mechanical Space	Scanning and TruView	$2,729	$3,396
	Subtotal	$7,063	$8,229

3D Modeling - In-House*		Cost Range low	Cost Range high
Exterior Fascade	Skeleton 3D Model	$1,250	$1,250
Mechanical Space	Skeleton 3D Model	$2,567	$2,667
	Subtotal	$3,817	$3,917

COBIE Survey and Integration - In-House**		Cost Range low	Cost Range high
COBIE Survey	Panasonic U1	$1,920	$2,347
COBIE/Model Integr	BIM Technician	$1,042	$2,083
	Subtotal	$2,962	$4,430
	Total (Cost Range)	**$19,860**	**$24,866**

Figure 28. COBIE to BIM Estimated Cost - Average Building.

Study Limitations

Availability of Technology: Prior to this study, the DPW personnel used the traditional paper and data entry method to collect information on components that required regular maintenance. The UW team researched various commercially available and recently developed technologies that would be suitable for collecting the COBIE data. Ultimately, the Adapx Digital Pen, Acer laptop with Access Forms, and the Panasonic U1 with Access Forms were selected for the comparative study against the traditional paper method. The technologies had certain limitations that should be considered:

- *Adapx Digital Pen.* Capturx for Excel Beta Program: Capturx software for Microsoft One Note and ArcGIS have been commercially available for over a year. However, during the time of this study, Capturx for Excel was still in development and only uploaded data in batches of approximately 20 rows at a time, in a non-chronological manner. Throughout the process and within strict time constraints, Adapx continued to improve the beta program.

- *Panasonic U-1 Pre-production Model*. The UW team deemed the U-1 as the best available ultra-mobile PC to collect COBIE data. Panasonic offered free use of a U-1 pre-production model for use in this study, which did not have the full functionality and responsiveness as its release model, but was still technologically superior to other UMPCs.

- *Access Forms for Acer Laptop and U-1 Not Fully Developed.* Access forms were created to facilitate the COBIE collection process on the Acer laptop and U-1; however, the programs were not fully developed to the desired level of the UW team, due to time constraints.

<u>Availability of Facilities and Information.</u> Selection of the facilities to be used in this study was a process that required facility occupant coordination and consensus amongst key project members. Once the facilities were selected, facility as-built drawings were available for only one of four building. Obtaining current as-built drawings for the other buildings required additional coordination with the various other departments in the DPW or the Army Corps of Engineers, or the UW team sorting through file archives. These necessary activities placed additional stress on short time constraints.

<u>Availability of Personnel.</u> The conduction of the field tests (FRAs) and the creation of the Access forms were challenging tasks due to the physical lack of personnel.

- *FRAs.* The study was launched towards the end of the UW Spring quarter, after which the call for the Field Research Assistants required for this study's summer field tests was released/posted to engineering and architect schools electronic and wall bulletins. Responses were very limited, as many students had already secured internships or made other summer plans.

- *Specialists for Access.* No UW students responded to the call to UW students for computer programmers to create the Access forms for the field studies. Third party consultants were successfully hired one week prior to the start of field studies. The consultants created partially-developed Access forms as an interface to the COBIE spreadsheets, so as to facilitate the efficient and accurate collection of COBIE data for field tests using the Acer laptop and Panasonic U1.

<u>Cross-Comparison of Technologies.</u> In ideal conditions, with more available time to conduct field tests, the survey teams would have been given field time to fully test all four technologies, in differing orders. This would have provided the FRAs true hands-on

experience, so they could have provided a more qualitatively rich comparison of the tools and methodologies to collect the COBIE data.

Survey Teams - Individual Traits. In ideal conditions, personnel with more similar levels of experience and backgrounds would have been selected to comprise the survey teams, so as to decrease the human factor biases of this study. The different comfort levels of using computers/software were also apparent across and within the teams. For example, some teams had more difficulty in collecting and computing spatial measurements than others.

Survey Procedures. The purpose of this study was to find the most effective/efficient method to collect information. As such, the surveyors were not restricted in the manner they collected information. The GRAs observed what procedures the surveyors employed to be most effective, and annotated what could be modified to increase productivity in future operations. The drawback of this approach is that variances in sub-task sequencing and procedures may influence productivity rates. For instance, the Acer laptop team worked closely together when they conducted the survey in a room-by-room basis on the first building, but then were often physically separated when they took a different approach (component-by-component) for the remaining buildings.

Survey Data Collection. The time to collect information differs between the tabs (Space, Component, Installation, Attributes). For example, the time it takes to measure and compute spatial information (one row of information) is almost equal to the time requirement to fill out a full attribute data sheet (5-21 rows of information). As a result, a team's productivity rates may have been influenced by the sequence in which they collected information.

Timing of Tasks. The teams surveyed the facilities and timed tasks in fixed sequences. However, the paper and Adapx methodologies required additional travel to office locations for data post-processing, and emergent logistical issues sometimes consumed field time. As a result of these variances, each survey team was allotted different times to perform the timed tasks.

Unrealized Capabilities of COBIE Technologies

Unexplored notepad capabilities of Acer laptop: The ACER notepad laptop featured a high-quality handwriting recognition tool that was not utilized. Use of this function would enable the data entry person to be mobile because both hands would not be required for typing. Instead, the data entry person could gather component information first-hand and not solely rely upon information fed by the data collector.

Potential for Access Forms: The Access forms that were used in this study were not fully developed but have great potential to surpass data entry efficiency over using Excel, especially if the Attribute fields are configured for common component types.

Conclusions

This study has identified alternative methods for capturing existing facility as-built BIM information and presented a comparative analysis of alternatives. Detailed information about the experimental process has been included in this report to facilitate understanding of the challenges, advantages, and disadvantages of each alternative. However, the most important findings of this study do not reside in the specific issues related to each methodology. Rather, they come to light through the lessons learned along the experimental process.

Three major challenges became obvious during the experimental process: logistical issues, operational issues, and user interface issues. In order to properly, effectively, and efficiently capture as-built BIM information of existing facilities all of these issues must be resolved.

Logistical Issues include access limitations to facilities and to specific areas within those facilities as well as ensuring that field surveyors have all necessary gear to perform their duties. Certain rooms or facilities are secured/sensitive areas, for which facility escorts must be coordinated ahead of time to avoid delays in the surveying process. Regarding surveying gear, it is necessary to properly account for all the tools that surveyors need and to provide the means for them to carry those tools in an ergonomically correct fashion in order to avoid fatigue and delays in the process. Therefore, proper coordination with escorts and minimizing the number of objects/devices to carry should be objectives of any field survey planning process.

Operational issues include the procedures followed by surveyors to capture information as well as the unavailability of updated drawings. Survey procedures should be standardized to facilitate data collection, enhance data reliability, and ensure completeness of the survey. Surveyors should collect in the field only the data that it is absolutely necessary and cannot be generated in any other way. This is especially important for attribute data. Attribute data should include only those attributes required for proper maintenance and operation of facilities. No additional information or attributes should be collected since this would significantly delay and complicate the data collection process. Regarding the accuracy of drawings, a building may have undergone several renovations but electronic drawings may not be updated or reliable in many instances. If as-built conditions deviate severely from the as-built drawings on file, the survey process is severely impacted. Therefore, developing standard procedures for data collection, minimizing the amount of data to collect in the field, and ensuring the accuracy of drawings should also be objectives of any field survey planning process.

User interface issues are related to the design of software applications used to collect field data. The applications should be created following a task-centered interface design process where the flow of the screens follow and support the tasks to be performed by the surveyors. The underline structure of the data and the relationships between data entries should be invisible to the surveyors. The software should support their activities in a natural, complete, and efficient manner. Therefore, developing data capturing software following a task-centered interface design should also be an objective of any field survey process.

Finally, geometry information should be captured keeping in mind the level of detail required to ensure that resources are not used in capturing more data than needed to generate a basic BIM model. Therefore, expensive technologies such as LIDAR should be used only when the level of detail provided merits its use. Simpler, less expensive approaches, such as the capturing of 2D geometries of floor plans should be utilized as much as possible. 3D models should be generated using in-house personnel to minimize costs.

Given all of the issues outlined above and the results of our analysis, we propose the following procedure for the implementation of a system to capture existing facility as-built BIM information:

1. Capture 2D geometries of floor plans if as-built conditions significantly differ from current drawings or if drawings are not available. Otherwise, update 2D geometries to reflect actual conditions if minimal changes are present.

2. Capture information about exterior elevations and complex areas such as mechanical rooms by taking advantage of LIDAR technology if this information is not available. Otherwise, update exterior elevation information if minimal changes are present.

3. Develop a basic (skeleton) 3D model of the facility using off-the-shelf BIM software by an in-house BIM technician. This model should include only the basic geometry and major visible items of the facility. Therefore, MEP systems would be modeled in a very limited fashion. However, such a model would be geometrically accurate and would support the addition of MEP information if required for a special project in the future. The model should also include all components and their attributes for which information will be captured in the field through the performance of a COBIE survey. Special attention should be paid to the development of a reduced list of attributes focused on selecting only those that are necessary for DPW and can be captured in the field.

4. Develop a data capture application following task-centered interface design principles to run on a mobile hand-held computer. This application would hide the COBIE spreadsheet from the user and present him/her only with the information needed to perform each task in the selected sequence. For example, if the sequence selected involves walking to a particular space and collecting all data from that space before moving to an adjacent space, then the application should start at that location and provide assistance to the user for locating the components to capture information about while clearly identifying the attributes to be captured for each component. Once all data is captured for the space, the system would automatically move on to the next space. Furthermore, all necessary information should be provided by the application, eliminating the need

to carry drawings or any other materials. Geometry data should not be captured as these can be extracted directly from the BIM model.

5. Plan the survey process to ensure the availability of proper escorts and develop a standard set of tools for surveyors to take to the field in an ergonomically correct fashion.

6. Perform field surveys.

7. Import the COBIE data from the field survey into the BIM model.

Appendix A: COBIE Survey Productivity Tables

Building 1: #9137

Task	ID	COBIE Tabs (Rows Completed)					Time		Productivity			Square	Remarks
		4	7	14	8	Sum	Time	Raw Rows per Minute	Team Size	Row/Min /Person	Combo AVG Row/Min	SF collected	
Task #1 Egress	Week 1A	1	1	1	10	13	0:20	0.65	2	0.33		129.3	Rows collected/identified
	Week 1B	1	1	1	0	3	0:10	0.30	2	0.15	0.24	129.3	Rows data entry completed
	Week 2A	3	9	1	126	139	0:50	2.78	1	2.78		396	Rows collected/identified
	Week 2B	1	2	2	18	23	1:00	1.15	1	1.15	1.97	132	Rows collected and data entry
	Week 3A	1	7	7	32	47	0:30	1.07	2	0.53		129	Rows collected/identified
	Week 3B	1	0	7	0	8	0:02:05	3.50	1	3.50	2.02	129	Rows data entry completed (Correction only not download time)
	Week 4A	1	13	13	186	213	1:00	3.55	1	3.55		128	Rows collected/identified
	Week 4B	1	5	5	55	66	1:00	1.10	1	1.10	2.33	128	Rows collected and data entry
Task #2 Pod 1: Common Area	Week 1A	2	6	6	52	66	0:45	1.47	2	0.73		120.86	Rows collected/identified
	Week 1B	2	3	6	0	11	0:20	0.55	2	0.28	0.50	120.86	Rows data entry completed
	Week 2A	4	13	0	104	121	1:00	2.02	1	2.02		199	Rows collected/identified
	Week 2B	0	3	4	41	48	1:00	2.40	1	2.40	2.21	0	Rows collected and data entry
	Week 3A	3	13	13	62	91	0:45	2.02	2	1.01		160.3	Rows collected/identified
	Week 3B	3	0	4	0	7	0:01:30	4.18	1	4.18	2.60	160.3	Rows data entry completed (Correction only not download time)
	Week 4A	4	13	13	130	160	1:00	2.67	1	2.67		187.56	Rows collected/identified
	Week 4B	3	12	12	117	144	1:00	2.40	1	2.40	2.53	175.26	Rows collected and data entry
Task #3 Pod 2: Bedroom	Week 1A	4	11	11	114	140	1:00	2.33	2	1.17		272.98	Rows collected/identified
	Week 1B	4	0	11	0	15	0:25	0.60	2	0.30	0.73	272.98	Rows data entry completed
	Week 2A	7	16	0	124	147	1:00	2.45	1	2.45		558	Rows collected/identified
	Week 2B	1	16	16	32	65	1:00	3.25	1	3.25	2.85	155	Rows collected and data entry
	Week 3A	8	17	17	114	156	1:00	2.60	2	1.30		567.21	Rows collected/identified
	Week 3B	2	0	0	0	2	0:01:00	1.90	1	1.90	1.60	567.21	Rows data entry completed (Correction only not download time)
	Week 4A	5	15	15	176	211	1:00	3.52	1	3.52		414.17	Rows collected/identified
	Week 4B	5	13	13	160	191	1:00	3.18	1	3.18	3.35	414.17	Rows collected and data entry
Task #4 Pod 3: Hallway	Week 1A	5	12	12	76	105	1:00	1.75	2	0.88		299.27	Rows collected/identified
	Week 1B	5	5	12	0	22	0:30	0.73	2	0.37	0.62	299.27	Rows data entry completed
	Week 2A	10	22	2	215	249	1:00	4.15	1	4.15		681	Rows collected/identified
	Week 2B	10	2	2	22	36	1:00	1.80	1	1.80	2.98	681	Rows collected and data entry
	Week 3A	1	11	11	38	61	1:00	1.02	2	0.51		144	Rows collected/identified
	Week 3B	1	0	0	0	1	0:00:30	1.90	1	1.90	1.21	144	Rows data entry completed (Correction only not download time)
	Week 4A	10	15	15	55	95	1:00	1.58	1	1.58		688.4	Rows collected/identified
	Week 4B	10	12	12	37	71	1:00	1.18	1	1.18	1.38	688.4	Rows collected and data entry
Task #5 Mechanical	Week 1A	1	11	11	16	39	0:30:00	1.30	2	0.65		294.58	Rows collected/identified
	Week 1B	1	4	11	0	16	0:15:00	1.07	2	0.53	0.59	294.58	Rows data entry completed
	Week 2A	1	13	4	18	36	0:34	1.06	1	1.06		176	Rows collected/identified
	Week 2B	1	13	13	0	27	0:54	1.35	1	1.35	1.20	176	Rows collected and data entry
	Week 3A	1	11	11	6	29	0:30	0.97	2	0.48		282.5	Rows collected/identified
	Week 3B	1	0	0	0	14	0:04:05	3.14	1	3.14	1.81	282.5	Rows data entry completed (Correction only not download time)
	Week 4A	2	22	22	27	73	1:00	1.22	1	1.22		437.7	Rows collected/identified
	Week 4B	1	13	13	17	44	1:00	0.73	1	0.73	0.98	292.13	Rows collected and data entry

Notes:

1. The values for Wk2 and Wk4 have been modified from version1 of this file to show total rows collected/identified.
2. Since the FRAs had to search the preloaded component or enter a new component for every Installation, they received "Rows collected/identified" credit for at least the number of Installation IDs they collected.
3. Since the FRAs for Wk2 and Wk4 had to verify the Component ID to complete data entry for Installation, they received data entry Component credit for at least the number of Installation IDs they inputted, even if the Component was preloaded
4. Since the FRAs for Wk1 and Wk3 only had to input or verify their handwritten notes during data entry, they did not receive any data entry credit for preloaded information (e.g. they receive raw data entry scores)
5. Data upload factor of 40 rows/min computed in Week 3B (Adapx Data Entry) Raw Rows per Minute
6. Software compensation factor of 3x Row Sum computed in Week 2B (Acer Data Entry) Raw Rows per Minute

Building 2: #3218

Task	ID	COBIE Tabs (Rows Completed)					Time		Productivity			Square	Remarks
		4	7	14	8	Sum	Time	Rows per Minute	Team Size	Row/Min /Person	Combo AVG Row/Min	SF collected	
Task #1: Dayroom	Week 1A	2	7	7	123	139	0:45	3.09	2	1.54		1225	Rows collected/identified
	Week 1B	2	7	7	11	27	0:30	0.90	2	0.45	1.00	1225	Rows data entry completed (Correction only not download time)
	Week 2A	4	17	0	257	278	1:00	4.63	1	4.63		2225.7	Rows collected/identified
	Week 2B	4	9	6	0	19	1:00	0.95	1	0.95	2.79	2147.7	Rows collected and data entry; Tab 14 all NA
	Week 3A	2	14	14	113	143	0:45	3.18	2	1.59		1072	Rows collected/identified
	Week 3B	0	0	14	21	35	9:44	3.30	1	3.30	2.44	1072	Rows data entry completed (Correction only not download time)
	Week 4A	2	12	12	174	200	1:00	3.33	1	3.33		1305.5	Rows collected/identified
	Week 4B	1	6	6	104	117	1:00	1.95	1	1.95	2.64	565.11	Rows collected and data entry
Task #2 Egress	Week 1A	2	7	7	76	92	0:30	3.07	2	1.53		341.48	Rows collected/identified
	Week 1B	2	7	7	11	27	0:20	1.35	2	0.68	1.10	341.48	Rows data entry completed
	Week 2A	6	8	0	65	79	1:00	1.32	1	1.32		518	Rows collected/identified; Tab 14 all NA
	Week 2B	3	2	2	13	20	1:00	1.00	1	1.00	1.16	322	Rows collected and data entry
	Week 3A	2	11	10	85	108	0:30	3.60	2	1.80		125	Rows collected/identified
	Week 3B	0	0	0	20	20	5:31	3.32	1	3.32	2.56	125	Rows data entry completed
	Week 4A	5	11	11	153	180	1:00	3.00	1	3.00		526.44	Rows collected/identified
	Week 4B	2	10	10	142	164	1:00	2.73	1	2.73	2.87	229.49	Rows collected and data entry
Task #3 Corridor w/ Bathrooms	Week 1A	4	15	15	173	207	0:30	6.90	2	3.45		391.61	Rows collected/identified
	Week 1B	4	15	15	0	34	0:30	1.13	2	0.57	2.01	391.61	Rows data entry completed
	Week 2A	7	16	11	218	252	1:15	3.36	1	3.36		2521.91	Rows collected/identified
	Week 2B	7	11	8	8	34	1:15	1.70	1	1.70	2.53	2521.91	Rows collected and data entry; 11 filled but 3 incorrect w/o install info
	Week 3A	6	11	10	105	132	0:45	2.93	2	1.47		1246.5	Rows collected/identified
	Week 3B	0	0	0	20	20	6:43	2.77	1	2.77	2.12	1246.5	Rows data entry completed (Correction only not download time)
	Week 4A	8	22	22	314	366	1:15	4.88	1	4.88		1004.53	Rows collected/identified
	Week 4B	8	16	16	163	203	1:15	2.71	1	2.71	3.79	1004.53	Rows collected and data entry
Task #4 Mech	Week 1A	1	8	8	23	40	0:20	2.00	2	1.00		169.72	Rows collected/identified
	Week 1B	1	8	8	12	29	0:20	1.45	2	0.73	0.86	169.72	Rows data entry completed
	Week 2A	1	9	8	21	39	0:34	1.15	1	1.15		816	Rows collected/identified
	Week 2B	1	9	9	10	29	0:47	1.45	1	1.45	1.30	816	Rows collected and data entry
	Week 3A	1	7	7	26	41	0:30	1.37	2	0.68		825	Rows collected/identified
	Week 3B	0	0	0	0	0	-		1	0.00	0.34	825	Rows data entry completed (Correction only not download time)
	Week 4A	1	13	13	26	53	0:45	1.18	1	1.18		823.83	Rows collected/identified
	Week 4B	1	13	13	26	53	0:45	1.18	1	1.18	1.18	823.83	Rows collected and data entry
Task #5 Corridor (Left) Office	Week 1A	5	16	16	195	232	0:30	7.73	2	3.87		1283.44	Rows collected/identified
	Week 1B	5	16	16	7	44	0:30	1.47	2	0.73	2.30	1283.44	Rows data entry completed
	Week 2A	6	22	4	294	326	1:15	4.35	1	4.35		1196.19	Rows collected/identified
	Week 2B	6	13	13	8	40	1:15	2.00	1	2.00	3.17	1196.69	Rows collected and data entry
	Week 3A	8	21	21	84	134	1:00	2.23	2	1.12		1070	Rows collected/identified
	Week 3B	0	0	0	21	21	6:38	2.93	1	2.93	2.03	1070	Rows data entry completed (Correction only not download time)
	Week 4A	9	27	27	307	370	1:15	4.93	1	4.93		2158.41	Rows collected/identified
	Week 4B	9	11	11	118	149	1:15	1.99	1	1.99	3.46	2158.41	Rows collected and data entry

Notes:

1. The values for Wk2 and Wk4 have been modified from version1 of this file to show total rows collected/identified.
2. Since the FRAs had to search the preloaded component or enter a new component for every Installation, they received "Rows collected/identified" credit for at least the number of Installation IDs they collected.
3. Since the FRAs for Wk2 and Wk4 had to verify the Component ID to complete data entry for Installation, they received data entry Component credit for at least the number of Installation IDs they inputted, even if the Component was preloaded
4. Since the FRAs for Wk1 and Wk3 only had to input or verify their handwritten notes during data entry, they did not receive any data entry credit for preloaded information (e.g. they receive raw data entry scores)
5. Data upload factor of 40 rows/min computed in Week 3B (Adapx Data Entry) Raw Rows per Minute
6. Software compensation factor of 3x Row Sum computed in Week 2B (Acer Data Entry) Raw Rows per Minute

Building 3: #11751

Task	ID	COBIE Tabs (Rows Completed)					Time		Productivity			Square	Remarks
		4	7	14	8	Sum	Time	Rows per Minute	Team Size	Row/Min /Person	Combo AVG Row/Min	SF collected	
Task #1 Mech	Week 1A	1	6	7	11	25	0:20	1.25	2	0.63		425.61	Rows collected/identified
	Week 1B	1	6	7	11	25	0:19	1.32	2	0.66	0.64	425.61	Rows data entry completed
	Week 2A	1	15	13	16	45	0:45	1.00	1	1.00		388.00	Rows collected/identified
	Week 2B	1	14	6	0	21	0:45	1.05	1	1.05	1.03	388.00	Rows collected and data entry
	Week 3A	1	7	7	11	26	0:20	1.30	2	0.65		421.00	Rows collected/identified
	Week 3B	0	5	6	0	11	0:08	1.32	1	1.32	0.98	421.00	Rows data entry completed (Correction only not download time)
	Week 4A	2	22	22	24	70	0:45	1.56	1	1.56		591.56	Rows collected/identified
	Week 4B	1	13	13	13	40	0:45	0.89	1	0.89	1.22	417.01	Rows collected and data entry
Task #2 Egress	Week 1A	2	5	5	64	76	0:30	2.53	2	1.27		332.98	Rows collected/identified
	Week 1B	2	5	5	21	33	:20	1.65	2	0.83	1.05	332.98	Rows data entry completed
	Week 2A	3	12	0	144	159	1:00	2.65	1	2.65		343.30	Rows collected/identified; error in counting smoke sensor for two non existent
	Week 2B	3	10	10	16	39	1:00	1.95	1	1.95	2.30	343.30	Rows collected and data entry
	Week 3A	1	10	10	80	101	0:30	3.37	2	1.68		411.00	Rows collected/identified
	Week 3B	0	6	9	22	37	0:10	3.14	1	3.14	2.41	411.00	Rows data entry completed (Correction only not download time)
	Week 4A	4	13	13	154	184	1:00	3.07	1	3.07		963.03	Rows collected/identified
	Week 4B	3	12	12	144	171	1:00	2.85	1	2.85	2.96	736.56	Rows collected and data entry
Task #3 Multi-function	Week 1A	2	21	21	351	395	0:40	9.88	2	4.94		3988.54	Rows collected/identified
	Week 1B	2	21	21	318	362	0:40	9.05	2	4.53	4.73	3988.54	Rows data entry completed
	Week 2A	7	13	4	30	54	1:00	0.90	1	0.90		7309.16	Rows collected/identified
	Week 2B	6	13	3	16	38	1:00	1.90	1	1.90	1.40	2967.60	Rows collected and data entry; 3 install rows entered NA
	Week 3A	4	46	46	57	153	0:40	3.83	2	1.91		5626.50	Rows collected/identified
	Week 3B	1	2	1	24	28	0:07	3.45	1	3.45	2.68	5626.50	Rows data entry completed (Correction only not download time)
	Week 4A	3	4	42	732	781	1:00	13.02	1	13.02		5820.77	Rows collected/identified
	Week 4B	2	3	28	364	397	1:00	6.62	1	6.62	9.82	5674.85	Rows collected and data entry
Task #4 Corridor (Bath)	Week 1A	3	6	10	96	115	0:40	2.88	2	1.44		560.95	Rows collected/identified
	Week 1B	3	6	10	69	88	0:40	2.20	2	1.10	1.27	560.95	Rows data entry completed
	Week 2A	8	25	5	241	279	1:00	4.65	1	4.65		796.21	Rows collected/identified
	Week 2B	8	18	16	0	42	1:00	2.10	1	2.10	3.38	796.21	Rows collected and data entry
	Week 3A	8	23	23	137	191	1:00	3.18	2	1.59		761.00	Rows collected/identified
	Week 3B	0	0	0	21	21	0:05	3.45	1	3.45	2.52	761.00	Rows data entry completed (Correction only not download time)
	Week 4A	7	5	17	296	325	1:00	5.42	1	5.42		835.34	Rows collected/identified
	Week 4B	7	4	13	262	286	1:00	4.77	1	4.77	5.09	835.34	Rows collected and data entry
Task #5 Corridor (Office)	Week 1A	3	4	10	103	120	0:30	4.00	2	2.00		764.26	Rows collected/identified
	Week 1B	3	4	10	44	61	0:30	2.03	2	1.02	1.51	764.26	Rows data entry completed
	Week 2A	14	29	0	335	378	1:00	6.30	1	6.30		1683.00	Rows collected/identified
	Week 2B	9	22	14	0	45	1:00	2.25	1	2.25	4.28	1114.23	Rows collected and data entry
	Week 3A	16	30	30	41	117	1:00	1.95	2	0.98		2077.70	Rows collected/identified
	Week 3B	15	0	15	0	30	0:04	5.88	1	5.88	3.43	2077.70	Rows data entry completed (Correction only not download time)
	Week 4A	15	10	28	414	467	1:00	7.78	1	7.78		2102.36	Rows collected/identified
	Week 4B	15	10	18	267	310	1:00	5.17	1	5.17	6.48	2102.36	Rows collected and data entry

Notes:
1. The values for Wk2 and Wk4 have been modified from version1 of this file to show total rows collected/identified.
2. Since the FRAs had to search the preloaded component or enter a new component for every Installation, they received "Rows collected/identified" credit for at least the number of Installation IDs they collected.
3. Since the FRAs for Wk2 and Wk4 had to verify the Component ID to complete data entry for Installation, they received data entry Component credit for at least the number of Installation IDs they inputted, even if the Component was preloaded
4. Since the FRAs for Wk1 and Wk3 only had to input or verify their handwritten notes during data entry, they did not receive any data entry credit for preloaded information (e.g. they receive raw data entry scores)
5. Data upload factor of 40 rows/min computed in Week 3B (Adapx Data Entry) Raw Rows per Minute
6. Software compensation factor of 3x Row Sum computed in Week 2B (Acer Data Entry) Raw Rows per Minute

BLDG 9137	Occupied Spaces - Productivity & Manhours					Mechanical Space - Productivity & Manhours				
ID	Average Row/Min/Person	Bldg 9137 Total SF	Average Row/SF	Est Total Rows/Bldg	Est Mnhrs to Survey Occupied Space	Average Row/Min/Person	Bldg 9137 Total SF	Average Row/SF	Est Total Rows/Mech	Est Mnhrs to Survey Mech Space
Week 1A - Paper_Collect	1.93	34337.99	0.49	16825.62	145.45	0.76	607.52	0.15	91.13	2.00
Week 1B - Paper_Input	0.92	34337.99	0.49	16825.62	306.38	0.64	607.52	0.15	91.13	2.38
Week 2A - Acer_Collect	3.30	34337.99	0.49	16825.62	85.08	1.07	607.52	0.15	91.13	1.42
Week 2B - Acer_Input	1.87	34337.99	0.49	16825.62	149.96	1.28	607.52	0.15	91.13	1.19
Week 3A - Adapx_Collect	1.29	34337.99	0.49	16825.62	217.28	0.61	607.52	0.15	91.13	2.51
Week 3B - Adapx_Input	3.31	34337.99	0.49	16825.62	84.72	1.49	607.52	0.15	91.13	1.02
Week 4A - U1_Collect	4.73	34337.99	0.49	16825.62	59.30	1.32	607.52	0.15	91.13	1.15
Week 4B - U1_Input	3.05	34337.99	0.49	16825.62	91.83	0.93	607.52	0.15	91.13	1.63

BLDG 3218	Occupied Spaces - Productivity & Manhours					Mechanical Space - Productivity & Manhours				
ID	Average Row/Min/Person	Bldg 3218 Total SF	Average Row/SF	Est Total Rows/Bldg	Est Mnhrs to Survey Occupied Space	Average Row/Min/Person	Bldg 3218 Total SF	Average Row/SF	Est Total Rows/Mech	Est Mnhrs to Survey Mech Space
Week 1A - Paper_Collect	1.93	40419.10	0.25	10104.78	87.35	0.76	800.65	0.10	80.07	1.76
Week 1B - Paper_Input	0.92	40419.10	0.25	10104.78	184.00	0.64	800.65	0.10	80.07	2.09
Week 2A - Acer_Collect	3.30	40419.10	0.25	10104.78	51.09	1.07	800.65	0.10	80.07	1.25
Week 2B - Acer_Input	1.87	40419.10	0.25	10104.78	90.06	1.28	800.65	0.10	80.07	1.04
Week 3A - Adapx_Collect	1.29	40419.10	0.25	10104.78	130.49	0.61	800.65	0.10	80.07	2.20
Week 3B - Adapx_Input	3.31	40419.10	0.25	10104.78	50.88	1.49	800.65	0.10	80.07	0.90
Week 4A - U1_Collect	4.73	40419.10	0.25	10104.78	35.61	1.32	800.65	0.10	80.07	1.01
Week 4B - U1_Input	3.05	40419.10	0.25	10104.78	55.15	0.93	800.65	0.10	80.07	1.43

BLDG 11751	Occupied Spaces - Productivity & Manhours					Mechanical Space - Productivity & Manhours				
ID	Average Row/Min/Person	Bldg 11751 Total SF	Average Row/SF	Est Total Rows/Bldg	Est Mnhrs to Survey Occupied Space	Average Row/Min/Person	Bldg 11751 Total SF	Average Row/SF	Est Total Rows/Mech	Est Mnhrs to Survey Mech Space
Week 1A - Paper_Collect	1.93	24461.39	0.20	4892.28	42.29	0.76	456.62	0.09	41.10	0.90
Week 1B - Paper_Input	0.92	24461.39	0.20	4892.28	89.09	0.64	456.62	0.09	41.10	1.07
Week 2A - Acer_Collect	3.30	24461.39	0.20	4892.28	24.74	1.07	456.62	0.09	41.10	0.64
Week 2B - Acer_Input	1.87	24461.39	0.20	4892.28	43.60	1.28	456.62	0.09	41.10	0.54
Week 3A - Adapx_Collect	1.29	24461.39	0.20	4892.28	63.18	0.61	456.62	0.09	41.10	1.13
Week 3B - Adapx_Input	3.31	24461.39	0.20	4892.28	24.63	1.49	456.62	0.09	41.10	0.46
Week 4A - U1_Collect	4.73	24461.39	0.20	4892.28	17.24	1.32	456.62	0.09	41.10	0.52
Week 4B - U1_Input	3.05	24461.39	0.20	4892.28	26.70	0.93	456.62	0.09	41.10	0.73

BLDG 3369	Occupied Spaces - Productivity & Manhours					Mechanical Space - Productivity & Manhours				
ID	Average Row/Min/Person	Bldg 11751 Total SF	Average Row/SF	Est Total Rows/Bldg	Est Mnhrs to Survey Occupied Space	Average Row/Min/Person	Bldg 11751 Total SF	Average Row/SF	Est Total Rows/Mech	Est Mnhrs to Survey Mech Space
Week 1A - Paper_Collect	1.93	29378.81	0.31	9205.36	79.58	0.76	803.53	0.10	80.35	1.77
Week 1B - Paper_Input	0.92	29378.81	0.31	9205.36	167.62	0.64	803.53	0.10	80.35	2.10
Week 2A - Acer_Collect	3.30	29378.81	0.31	9205.36	46.55	1.07	803.53	0.10	80.35	1.25
Week 2B - Acer_Input	1.87	29378.81	0.31	9205.36	82.04	1.28	803.53	0.10	80.35	1.05
Week 3A - Adapx_Collect	1.29	29378.81	0.31	9205.36	118.87	0.61	803.53	0.10	80.35	2.21
Week 3B - Adapx_Input	3.31	29378.81	0.31	9205.36	46.35	1.49	803.53	0.10	80.35	0.90
Week 4A - U1_Collect	4.73	29378.81	0.31	9205.36	32.44	1.32	803.53	0.10	80.35	1.02
Week 4B - U1_Input	3.05	29378.81	0.31	9205.36	50.24	0.93	803.53	0.10	80.35	1.43

Appendix B: COBIE Survey Preparation Activities

Building 1: #9137 Survey Preload/Preparation Time Card							
Date	Time In	Time Out	Total Time	Building	Remarks	Factor*	Full Bldg
5-Jul-08	19:00	19:20	0:20	9137	File Preparation	3	1:00
5-Jul-08	19:45	20:30	0:45	9137	Document Review	3	2:15
6-Jul-08	10:30	11:00	0:30	9137	Document Copy	1	0:30
6-Jul-08	11:15	12:00	0:45	9137	Tab 1-6	3	2:15
6-Jul-08	12:00	12:50	0:50	9137	Scan Enlarged Plans Assign Component Numbers for Doors and Windows	3	2:30
6-Jul-08	13:15	14:00	0:45	9137	Tab 7: Doors, Windows, Basic Plumbing; Incomplete	3	2:15
6-Jul-08	14:00	14:30	0:30	9137	Tab 4: Correct Room Numbers and Add Space Functions	3	1:30
6-Jul-08	14:30	14:45	0:15	9137	Tab 7: Doors, Windows, Basic Plumbing; Incomplete	3	0:45
6-Jul-08	15:00	15:45	0:45	9137	Tab 7: Doors, Windows, Basic Plumbing; Modules 1-3	3	2:15
6-Jul-08	15:45	16:00	0:15	9137	Tab 7: Fire Protection	1	0:15
6-Jul-08	16:20	17:15	0:55	9137	Tab 7: Fire Protection, Plumbing & Mechanical Schedules	1	0:55
			6:35				**16:25**
* Note: Original time for 1/3 of Bldg 9137							

Building 2: #3218 Survey Preload/Preparation Time Card							
Date	Time In	Time Out	Total Time	Building	Remarks	Factor*	Full Bldg
2-Jul-08	16:00	17:30	1:30	3218	Reviewing Floor Plans Scans	3	4:30
5-Jul-08	19:20	19:45	0:25	3218	File Preparation	3	1:15
6-Jul-08	10:30	11:00	0:30	3218	Document Copy	1	0:30
			2:25				**6:15**
* Note: Original time for 1/3 of Bldg 3218							

Building 3: #11751 Survey Preload/Preparation Time Card							
Date	Time In	Time Out	Total Time	Building	Remarks	Factor*	Full Bldg
4-Jul-08	15:50	17:30	1:40	11751	Tab 1-4	2	3:20
4-Jul-08	18:30	19:00	0:30	11751	Components--Drawing Review	2	1:00
6-Jul-08	10:30	11:00	0:30	11751	Document Copy	1	0:30
6-Jul-08	19:30	20:45	1:15	11751	Tab 7: Doors Windows	2	2:30
			3:55				**7:20**
* Note: Original time for 1/2 of Bldg 11751							

Building 3369 Survey Preload/Preparation Time Card							
Date	Time In	Time Out	Total Time	Building	Remarks	Factor*	Full Bldg
22-Jun-08	15:00	16:00	1:00	3369	Document Review	2	2:00
22-Jun-08	15:00	16:20	1:20	3369	Photography and File Organization	2	2:40
23-Jun-08	13:00	13:30	0:30	3369	Develop Survey Sequence(1-50)	1	0:30
23-Jun-08	15:15	16:15	1:00	3369	Tabs 1-4	2	2:00
30-Jun-08	15:30	16:30	1:00	3369	Tab 7: Doors	2	2:00
30-Jun-08	16:45	17:15	0:30	3369	Photography for Component Numbering of Windows	2	1:00
30-Jun-08	17:30	18:00	0:30	3369	Window Component Assignments and Load Eata	2	1:00
30-Jun-08	22:20	23:00	0:40	3369	Tab 7: Plumbing Fixtures	1	0:40
1-Jul-08	15:20	17:10	1:50	3369	Tab 7: Door/Window Types Noted, Plumbing Fixtures, Fire Alarm/Detection	2	3:40
			8:20				**15:30**
* Note: Original time for 1/2 of Bldg 3369							

Appendix C: COBIE Technology Equipment Costs

Computer Printing		Recommendations	Unit Price	Unit
Laser printer toner - cyan	Lexmark C920 Cyan Toner Cartridge		$310.00	Each
Laser printer toner - magenta	Lexmark C920 Magenta Toner Cartridge		$310.00	Each
Laser printer toner - yellow	Lexmark C920 Yellow Toner Cartridge		$310.00	Each
Laser printer toner - black	Lexmark C920 Black Toner Cartridge		$214.00	Each
Color Prints - 8.5" x 11"	Yield: Up to 14,000 standard pages based on approximately 5% coverage.		$0.08	Ea 8.5x11
Color prints - 11" x 17"	Yield: Up to 7,500 11x17 pages based on approximately 5% coverage.	30 Rows per COBIE sheet	$0.16	Ea 11x17
B/W Prints - 8.5" x 11'	Yield: Up to 15,000 pages based on approximately 5% coverage.	Avg 15 Rows per data sheet; 6 components per	$0.01	Ea 8.5x11
B/W Prints - 11" x 17"	Yield: Up to 7,500 11x17 pages based on approximately 5% coverage.	30 Rows per sheet	$0.03	Ea 11x17

Common Data Collection Tools & Accessories		Recommendations	Unit Price	Unit	Quantity per Month	Quantity per Year	Monthly Cost	Yearly Cost
Laser Measuring Device	Hilti PD 4 Laser Range Meter	2 units every 3 years	$199.00	Each	0.06	0.67	$11.06	$132.67
Construction Calculator	Calculated Industries Construction Master 5	2 units every 3 years	$50.00	Each	0.06	0.67	$2.78	$33.33
Toolbelt	Poly Suspension Tool Rig	1 unit every 3 years	$50.00	Each	0.03	0.33	$1.39	$16.67
Portable wheeled cart	Rubbermaid® Metal Fold 'N Roll Cart System, Black	1 unit every 3 years	$89.00	Each	0.03	0.33	$2.47	$29.67
25' metal tape measure	Stanley 25 Ft. Leverlock Tape Measure	2 units every 3 years	$9.00	Each	0.06	0.67	$0.50	$6.00
LED Flashlight	Gerber Infinity Ultra LED Flashlight	2 units every 3 years	$21.00	Each	0.06	0.67	$1.17	$14.00
Pens and Mechanical Pencils			$0.50	Each	12	144	$6.00	$72.00
				Subtotal Common Tools			**$25.36**	**$304.33**

Office Computer		Recommendations	Unit Price	Unit	Quantity per Month	Quantity per Year	Monthly Cost	Yearly Cost
Desktop Computer (3.2 Ghz, 1Gb RAM, 80Gb harddrive, onboard graphics card thats embedded in motherboard, Windows XP)	OptiPlex 755 Desktop	1 unit every 3 years	$1,325.00	Each	0.03	0.33	$36.81	$441.67
17" flat screen	Dell 17 inch E178FP Flat Panel, Analog	1 unit every 3 years	$199.00	Each	0.03	0.33	$5.53	$66.33
3-Yr IT Support	3 Year ProSupport for IT and 3 Year 4HR 7x24 Onsite Service	1 contract every 3 years	$149.00	Lump Sum	0.03	0.33	$4.14	$49.67
Color Laser Printer	Lexmark C920	1/10 unit every 3 years (shared)	$1,713.00	Each	0.0028	0.03	$4.76	$57.10
				Subtotal Office Computer			**$51.23**	**$614.77**

Paper Forms and Data Entry		Recommendations		Unit Price	Unit	Quantity per Month	Quantity per Year	Monthly Cost	Yearly Cost
Common Data Collection Tools & Accessories				-	-	-	-	**$25.36**	**$304.33**
Office Computer				-	-	-	-	**$51.23**	**$614.77**
Clipboards, 8.5"x11"			2 units every 6 months	$1.00	Each	0.33	4	$0.33	$4.00
Clipboards, 11"x17"			3 units every 6 months	$15.00	Each	0.5	6	$7.50	$90.00
B&W COBIE sheets		65	COBIE Sheets per Bldg	$0.03	Ea 11x17	0.82	9.89	$1.53	$18.34
B&W data sheets		96	Data Sheets per Bldg	$0.01	Ea 8.5x11	0.82	9.89	$1.13	$13.54
					Total Equipment Expenses			**$87.08**	**$1,044.98**
					Est Equip Expense per Bldg			**$105.68**	

ACER Travel Mate C300		Recommendations		Unit Price	Unit	Quantity per Month	Quantity per Year	Monthly Cost	Yearly Cost
Common Data Collection Tools & Accessories				-	-	-	-	**$25.36**	**$304.33**
Clipboards, 8.5"x11"			1 unit every 6 months	$1.00	Each	0.17	2	$0.17	$2.00
Clipboards, 11"x17"			1 unit every 6 months	$15.00	Each	0.17	2	$2.50	$30.00
Foldable chair	GCI Outdoor Quik-E-Seat		2 units every 3 years	$29.00	Each	0.06	0.67	$1.61	$19.33
Foldable table	Personal Table		1 unit every 3 years	$28.00	Each	0.03	0.33	$0.78	$9.33
ACER notebook	Travelmate C300 - TMC301XCi		1 unit every 3 years	$2,017.00	Each	0.028	0.33	$56.03	$672.33
Mini mouse for TabletPC	Logitech Notebook Optical Mouse Plus		2 units every 3 years	$11.00	Each	0.056	0.67	$0.61	$7.33
B&W COBIE sheets (only Tab 14 - Installation)		26	COBIE Tab 14 Sheets per Bldg	$0.03	Ea 11x17	1.53	18.40	$1.14	$13.65
B&W data sheets		96	Data Sheets per Bldg	$0.01	Ea 8.5x11	1.53	18.40	$2.10	$25.20
					Total Equipment Expenses			**$90.29**	**$1,083.51**
					Est Equip Expense per Bldg			**$58.89**	

Adapx Digital Pen			Recommendations	Unit Price	Unit	Quantity per Month	Quantity per Year	Monthly Cost	Yearly Cost
Common Data Collection Tools & Accessories				-	-	-	-	**$25.36**	**$304.33**
Office Computer				-	-	-	-	**$51.23**	**$614.77**
Clipboards, 11"x17"			4 units every 6 months	$15.00	Each	0.67	8	$10.00	$120.00
Capturx for Excel single license	Capturx for MS Office Excel 2007		One-time Purchase	$1,800.00	Each		2		$3,600.00
One Note Set w/pen	Capturx for MS Office OneNote 2007 Kit		One-time Purchase	$349.00	Each		2		$698.00
MS One Note single license	Microsoft OneNote 2007		Upgrade every 2	$99.00	Each	0.042	0.5	$4.13	$49.50
Replacement digital pen	Adapx Digital Pen Replacement		2 units every 3 years	$250.00	Each	0.056	0.67	$13.89	$166.67
Replacement ink	Digital Penx ink refill cartridges - 5 pack		2 units every 3 years	$10.00	Each	0.056	0.67	$0.56	$6.67
Color COBIE sheets		351	COBIE Sheets per Bldg	$0.16	Ea 11x17	1.21	14.52	$69.39	$832.66
					Total Equipment Expenses			**$174.55**	**$6,392.60**
					Est Equip Expense per Bldg			**$440.39**	

Panasonic U-1			Recommendations	Unit Price	Unit	Quantity per Month	Quantity per Year	Monthly Cost	Yearly Cost
Common Data Collection Tools & Accessories				-	-	-	-	**$25.36**	**$304.33**
Clipboards, 8.5"x11"			1 unit every 6 months	$1.00	Each	0.17	2	$0.17	$2.00
Clipboards, 11"x17"			1 unit every 6 months	$15.00	Each	0.17	2	$2.50	$30.00
Foldable chair	GCI Outdoor Quik-E-Seat		2 units every 3 years	$29.00	Each	0.06	0.67	$1.61	$19.33
Foldable table	Personal Table		1 unit every 3 years	$28.00	Each	0.03	0.33	$0.78	$9.33
UMPC	Panasonic Toughbook U1 Fully Rugged		1 unit every 3 years	$2,499.00	Each	0.017	0.2	$41.65	$499.80
Mini mouse for UMPC	Logitech Notebook Optical Mouse Plus		2 units every 3 years	$11.00	Each	0.056	0.67	$0.61	$7.33
B&W COBIE sheets (only Tab 14 - Installation)		26	COBIE Tab 14 Sheets per Bldg	$0.03	Ea 11x17	2.29	27.43	$1.70	$20.35
B&W data sheets (estimate cost per sheet)		96	Data Sheets per Bldg	$0.01	Ea 8.5x11	2.29	27.43	$3.13	$37.57
					Total Equipment Expenses			**$52.14**	**$625.73**
					Est Equip Expense per Bldg			**$22.81**	

Appendix D: COBIE Technology Operational Costs

BLDG 9137 — COBIE Survey Operational Costs

ID	Hourly Rate	Operational Total Mnhrs	Operation Cost Subtotal	Team Operational Mnhrs	Team Operational Subtotal	Preparation Time	Preparation Cost	Total Operational Cost per Bldg
Week 1A - Paper_Collect	$20	147.45	$2,949.04					
Week 1B - Paper_Input	$20	308.76	$6,175.25	456	$9,124	16.42	$328.33	$9,453
Week 2A - Acer_Collect	$20	86.50	$1,729.99					
Week 2B - Acer_Input	$20	151.15	$3,022.95	238	$4,753	16.42	$328.33	$5,081
Week 3A - Adapx_Collect	$20	219.79	$4,395.76					
Week 3B - Adapx_Input	$20	85.74	$1,714.81	306	$6,111	16.42	$328.33	$6,439
Week 4A - U1_Collect	$20	60.45	$1,209.09					
Week 4B - U1_Input	$20	93.46	$1,869.24	154	$3,078	16.42	$328.33	$3,407

BLDG 3218 — COBIE Survey Operational Costs

ID	Hourly Rate	Operational Total Mnhrs	Operation Cost Subtotal	Team Operational Mnhrs	Team Operational Subtotal	Preparation Time	Preparation Cost	Total Operational Cost per Bldg
Week 1A - Paper_Collect	$20	89.11	$1,782.21					
Week 1B - Paper_Input	$20	186.09	$3,721.82	275	$5,504	6.25	$125.00	$5,629
Week 2A - Acer_Collect	$20	52.34	$1,046.86					
Week 2B - Acer_Input	$20	91.10	$1,822.06	143	$2,869	6.25	$125.00	$2,994
Week 3A - Adapx_Collect	$20	132.69	$2,653.86					
Week 3B - Adapx_Input	$20	51.78	$1,035.51	184	$3,689	6.25	$125.00	$3,814
Week 4A - U1_Collect	$20	36.63	$732.54					
Week 4B - U1_Input	$20	56.58	$1,131.64	93	$1,864	6.25	$125.00	$1,989

BLDG 11751	COBIE Survey Operational Costs							
ID	Hourly Rate	Operational Total Mnhrs	Operation Cost Subtotal	Team Operational Mnhrs	Team Operational Subtotal	Preparation Time	Preparation Cost	Total Operational Cost per Bldg
Week 1A - Paper_Collect	$20	43.19	$863.89					
Week 1B - Paper_Input	$20	90.16	$1,803.16	133	$2,667	7.33	$146.67	$2,814
Week 2A - Acer_Collect	$20	25.38	$507.57					
Week 2B - Acer_Input	$20	44.14	$882.77	70	$1,390	7.33	$146.67	$1,537
Week 3A - Adapx_Collect	$20	64.31	$1,286.16					
Week 3B - Adapx_Input	$20	25.09	$501.87	89	$1,788	7.33	$146.67	$1,935
Week 4A - U1_Collect	$20	17.76	$355.25					
Week 4B - U1_Input	$20	27.44	$548.72	45	$904	7.33	$146.67	$1,051

BLDG 3369	COBIE Survey Operational Costs							
ID	Hourly Rate	Operational Total Mnhrs	Operation Cost Subtotal	Team Operational Mnhrs	Team Operational Subtotal	Preparation Time	Preparation Cost	Total Operational Cost per Bldg
Week 1A - Paper_Collect	$20	81.34	$1,626.83					
Week 1B - Paper_Input	$20	169.72	$3,394.42	251	$5,021	15.50	$310.00	$5,331
Week 2A - Acer_Collect	$20	47.80	$956.00					
Week 2B - Acer_Input	$20	83.09	$1,661.81	131	$2,618	15.50	$310.00	$2,928
Week 3A - Adapx_Collect	$20	121.09	$2,421.73					
Week 3B - Adapx_Input	$20	47.25	$945.00	168	$3,367	15.50	$310.00	$3,677
Week 4A - U1_Collect	$20	33.46	$669.22					
Week 4B - U1_Input	$20	51.68	$1,033.56	85	$1,703	15.50	$310.00	$2,013

AVERAGE OF BLDGS 9137, 3218, 11751

	Occupied Spaces				
Team	Average Row/Min/Person	Average Total SF	Average Row/SF	Est Total Rows/Bldg	Est Mnhrs to Survey Occupied Space
Week 1A - Paper_Collect	1.93	33072.83	0.31	10362.82	89.58
Week 1B - Paper_Input	0.92	33072.83	0.31	10362.82	188.70
Week 2A - Acer_Collect	3.30	33072.83	0.31	10362.82	52.40
Week 2B - Acer_Input	1.87	33072.83	0.31	10362.82	92.36
Week 3A - Adapx_Collect	1.29	33072.83	0.31	10362.82	133.82
Week 3B - Adapx_Input	3.31	33072.83	0.31	10362.82	52.18
Week 4A - U1_Collect	4.73	33072.83	0.31	10362.82	36.52
Week 4B - U1_Input	3.05	33072.83	0.31	10362.82	56.56

	Mechanical Space				
Team	Average Row/Min/Person	Average Total SF	Average Row/SF	Est Total Rows/Mech	Est Mnhrs to Survey Mech Space
Week 1A - Paper_Collect	0.76	621.59	0.10	62.16	1.37
Week 1B - Paper_Input	0.64	621.59	0.10	62.16	1.62
Week 2A - Acer_Collect	1.07	621.59	0.10	62.16	0.97
Week 2B - Acer_Input	1.28	621.59	0.10	62.16	0.81
Week 3A - Adapx_Collect	0.61	621.59	0.10	62.16	1.71
Week 3B - Adapx_Input	1.49	621.59	0.10	62.16	0.70
Week 4A - U1_Collect	1.32	621.59	0.10	62.16	0.79
Week 4B - U1_Input	0.93	621.59	0.10	62.16	1.11

	COBIE Survey Operational Costs							
Team	Hourly Rate	Operational Total Mnhrs	Operation Cost Subtotal	Team Operational Mnhrs	Team Operational Subtotal	Preparation Time	Preparation Cost	Average Operational Cost per Bldg
Week 1A - Paper_Collect	$20	90.95	$1,818.95					
Week 1B - Paper_Input	$20	190.32	$3,806.45	281	$5,625	10.00	$200.00	$5,825
Week 2A - Acer_Collect	$20	53.37	$1,067.37					
Week 2B - Acer_Input	$20	93.17	$1,863.39	147	$2,931	10.00	$200.00	$3,131
Week 3A - Adapx_Collect	$20	135.53	$2,710.65					
Week 3B - Adapx_Input	$20	52.87	$1,057.49	188	$3,768	10.00	$200.00	$3,968
Week 4A - U1_Collect	$20	37.31	$746.20					
Week 4B - U1_Input	$20	57.67	$1,153.41	95	$1,900	10.00	$200.00	$2,100

	COBIE Survey Operational Costs				Output		Optimal Outputs (Human/Logistic	
Team	Team Operational Subtotal	Preparation Time	Preparation Cost	Average Operational Cost per Bldg	Est Bldgs Completed in 1 Month	Est Bldgs Completed in 1 Year	Optimal Bldgs Completed in 1 Month	Optimal Bldgs Completed in 1 Year
Paper	$5,625	10.00	$200.00	$5,825	0.82	9.89	0.82	9.89
Acer	$2,931	10.00	$200.00	$3,131	1.53	18.40	1.53	18.40
Adapx	$3,768	10.00	$200.00	$3,968	1.21	14.52	1.21	14.52
Panasonic U1	$1,900	10.00	$200.00	$2,100	2.29	27.43	2.29	27.43

Appendix E: Assumed Grade/Step for Hired Surveyors and Specialists (2008 Pay Schedules)

Salary Table 2008, GS Hourly Rate (Seattle) - Assumed Grade/Step for COBIE Surveyors

Grade	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10
1	$9.78	$10.11	$10.43	$10.76	$11.08	$11.27	$11.59	$11.92	$11.93	$12.24
2	$11.00	$11.26	$11.62	$11.93	$12.06	$12.42	$12.77	$13.13	$13.48	$13.84
3	$12.00	$12.40	$12.80	$13.20	$13.60	$14.00	$14.40	$14.80	$15.20	$15.60
4	$13.47	$13.92	$14.37	$14.82	$15.27	$15.72	$16.17	$16.61	$17.06	$17.51
5	$15.07	$15.57	$16.07	$16.58	$17.08	$17.58	$18.08	$18.58	$19.09	$19.59
6	$16.80	$17.36	$17.92	$18.48	$19.04	$19.60	$20.16	$20.72	$21.28	$21.84
7	$18.67	$19.29	$19.91	$20.53	$21.16	$21.78	$22.40	$23.02	$23.64	$24.27
8	$20.67	$21.36	$22.05	$22.74	$23.43	$24.12	$24.81	$25.50	$26.19	$26.88
9	$22.83	$23.60	$24.36	$25.12	$25.88	$26.64	$27.40	$28.16	$28.93	$29.69
10	$25.15	$25.98	$26.82	$27.66	$28.50	$29.34	$30.18	$31.01	$31.85	$32.69
11	$27.63	$28.55	$29.47	$30.39	$31.31	$32.23	$33.15	$34.07	$34.99	$35.92
12	$33.11	$34.22	$35.32	$36.42	$37.53	$38.63	$39.74	$40.84	$41.94	$43.05

Wage Table 2008, XG-XH (Seattle) - Assumed Grade/Step for COBIE Surveyors

XG-XH	XF-Rates					XG-Rates				
Grade	1	2	3	4	5	1	2	3	4	5
1	$14.21	$14.79	$15.37	$15.98	$16.58	$15.62	$16.28	$16.92	$17.57	$18.22
2	$15.43	$16.08	$16.72	$17.38	$18.01	$16.98	$17.68	$18.42	$19.10	$19.82
3	$16.66	$17.37	$18.05	$18.77	$19.45	$18.33	$19.10	$19.87	$20.62	$21.39
4	$17.92	$18.66	$19.40	$20.16	$20.89	$19.71	$20.52	$21.34	$22.19	$23.00
5	$19.15	$19.95	$20.75	$21.54	$22.33	$21.06	$21.94	$22.82	$23.70	$24.56
6	$20.39	$21.23	$22.09	$22.92	$23.77	$22.44	$23.38	$24.29	$25.23	$26.16
7	$21.62	$22.53	$23.42	$24.33	$25.22	$23.76	$24.77	$25.78	$26.76	$27.74
8	$22.85	$23.80	$24.77	$25.73	$26.66	$25.15	$26.18	$27.24	$28.29	$29.34
9	$23.85	$24.83	$25.83	$26.85	$27.85	$26.27	$27.35	$28.46	$29.55	$30.63
10	$24.60	$25.71	$26.76	$27.74	$28.78	$27.09	$28.25	$29.37	$30.52	$31.66

GS Schedule, Annual Salary (Seattle) - Assumed Grade/Step Equivalent for Full-Time 3D Modeler

Grade	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10
9	$47,655	$49,244	$50,833	$52,422	$54,011	$55,600	$57,189	$58,778	$60,367	$61,956
10	$52,479	$54,229	$55,978	$57,728	$59,477	$61,227	$62,977	$64,726	$66,476	$68,225
11	$57,657	$59,579	$61,501	$63,423	$65,345	$67,267	$69,189	$71,111	$73,033	$74,955
12	$69,107	$71,411	$73,715	$76,018	$78,322	$80,626	$82,930	$85,234	$87,538	$89,842
13	$82,178	$84,918	$87,658	$90,398	$93,138	$95,878	$98,618	$101,358	$104,097	$106,837

GS Schedule, Annual Salary (Seattle) - Assumed Grade/Step Equivalent for BIM Tech - COBIE/Model Integration

Grade	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10
5	$31,451	$32,499	$33,547	$34,595	$35,642	$36,690	$37,738	$38,786	$39,834	$40,881
6	$35,058	$36,227	$37,396	$38,564	$39,733	$40,902	$42,071	$43,239	$44,408	$45,577
7	$38,959	$40,258	$41,556	$42,854	$44,152	$45,450	$46,748	$48,046	$49,344	$50,642
8	$43,146	$44,584	$46,022	$47,461	$48,899	$50,337	$51,775	$53,213	$54,652	$56,090
9	$47,655	$49,244	$50,833	$52,422	$54,011	$55,600	$57,189	$58,778	$60,367	$61,956
10	$52,479	$54,229	$55,978	$57,728	$59,477	$61,227	$62,977	$64,726	$66,476	$68,225
11	$57,657	$59,579	$61,501	$63,423	$65,345	$67,267	$69,189	$71,111	$73,033	$74,955

Source: U.S. Office of Personnel Management Salaries and Wages
http://www.opm.gov/oca/08tables/indexGS.asp

Source: Department of Defense Civilian Personnel Mangement Service
http://www.cpms.osd.mil/wage/scheds/af/survey-sch/143/

Appendix F: COBIE Cost Tables

COBIE Survey Cost Tables - Equipment and Operational Costs per Building

Bldgs 9137

Occupied Space:	New barracks building, featuring quads of 3-bedroom suites with shared common area			
Occupied Area:	33730.48	sq ft		
Mechanical Space:	Rectangular, densely equipped space			
Mechanical Area:	607.52	sq ft		
Floors:	3			
Rooms:	380			
External Dimensions (W-L-H):	55.25	217.45	34.45	feet

Bldg 9137	Est Equipment Costs per Bldg		Operational Costs			TOTAL
	Common Data Collection Tools	Survey Technology Requirements	Preparation Cost	Data Collection	Data Entry	
Paper Forms	$5.24	$15.43	$328	$1,166	$1,281	**$2,797**
Acer Laptop	$18.08	$46.09	$328	$917	$5,226	**$6,535**
Adapx Digital Pen	$4.79	$6.04	$328	$2,977	$1,142	**$4,458**
Panasonic U1	$3.91	$10.06	$328	$450	$873	**$1,666**

Bldgs 3218

Occupied Space:	Old barracks building with offices on first floor, two floors of dorm rooms above, and basement storage			
Occupied Area:	39618.45	sq ft		
Mechanical Space:	Rectangular, open space; sparsely equipped			
Mechanical Area:	800.65	sq ft		
Floors:	4			
Rooms:	132			
External Dimensions (W-L-H):	38.83	217.67	37.91	feet

Bldg 3218	Est Equipment Costs per Bldg		Operational Costs			TOTAL
	Common Data Collection Tools	Survey Technology Requirements	Preparation Cost	Data Collection	Data Entry	
Paper Forms	$5.24	$15.43	$125	$709	$781	**$1,636**
Acer Laptop	$18.08	$46.09	$125	$558	$3,152	**$3,899**
Adapx Digital Pen	$4.79	$6.04	$125	$1,800	$700	**$2,636**
Panasonic U1	$3.91	$10.06	$125	$276	$532	**$947**

Bldgs 11751

Occupied Space: New Company HQ with admin on first floor, shower baths, and large adjoining storage bay w/mezzanine
Occupied Area: 24004.78 sq ft
Mechanical Space: Rectangular, densely equipped space
Mechanical Area: 456.62 sq ft
Floors: 2
Rooms: 70
External Dimensions (W-L-H): 121.23 165.52 28.00 feet

Bldg 11751	Est Equipment Costs per Bldg		Operational Costs			TOTAL
	Common Data Collection Tools	Survey Technology Requirements	Preparation Cost	Data Collection	Data Entry	
Paper Forms	$5.24	$15.43	$147	$344	$379	$891
Acer Laptop	$18.08	$46.09	$147	$271	$1,527	$2,009
Adapx Digital Pen	$4.79	$6.04	$147	$873	$340	$1,370
Panasonic U1	$3.91	$10.06	$147	$134	$258	$553

Bldgs 3369

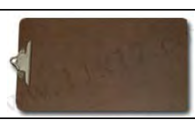
Occupied Space: Large Company HQ building w/meeting spaces on first floor, offices above, and two large adjoining storage bays
Occupied Area: 39618.45 sq ft
Mechanical Space: Rectangular, densely equipped space
Mechanical Area: 800.65 sq ft
Floors: 2
Rooms: 79
External Dimensions (W-L-H): 137.42 273.58 28.00 feet

Bldg 3369	Est Equipment Costs per Bldg		Operational Costs			TOTAL
	Common Data Collection Tools	Survey Technology Requirements	Preparation Cost	Data Collection	Data Entry	
Paper Forms	$5.24	$15.43	$310	$483	$535	$1,348
Acer Laptop	$18.08	$46.09	$310	$381	$2,122	$2,877
Adapx Digital Pen	$4.79	$6.04	$310	$1,217	$482	$2,020
Panasonic U1	$3.91	$10.06	$310	$190	$363	$877

Appendix G: COBIE, 2D, and 3D Technology Services/Vendors

Technology	Company	Address	Point of Contact	Contact Information
Digital Pen	Adapx	821 Second Avenue, Suite 1150 Seattle, WA 98104	David Hyres, Scott Lin	Office: 206-428-0800 Cell: 253-208-8164 Fax: 206-428-0801 Email: david.hyres@adapx.com Website: adapx.com
U1 Ultramobile PC	Panasonic		Bob Jaynes	Office: 703-791-2396 Cell: 973-970-0040 Email: bob_jaynes@panasonic.com Website: http://www.panasonic.com/
2D Floorplans	2D As-built Floorplans	1700 21st Avenue South Suite 100 Seattle, WA 98144	Steve Cramer	Office: 206-328-7410 Cell: 206-713-8044 Fax: 206-328-4764 Email: stevec@2dfloorplans.com Website: http://www.2dfloorplans.com
2D Floorplans	Lasertech Floorplans Ltd.	10161 Park Run Drive, Suite 150 Las Vegas, NV 89145-8859	Steve Orser	Office: 888-393-6655 Cell: 250-883-6853 Email: sorser@lt-fp.com Websit: www.lt-fp.com
3D Scanning and Modeling	David Evans & Associates	3700 Pacific Hwy. East, Suite 311 Tacoma, WA 98424	Sean Douthett	Office: 253-250-0616 Cell: 425-864-1358 Email: Smd@deainc.com Website: www.deainc.com
3D Scanning and Modeling	Documenta Surveys	3030 Bridgeway, Unit 221 Sausalito, CA 94965	Peter Borges	Office: 877-272-8458 Cell: 415-717-5589 Email: peter@documentasurveys.com Website: http://www.documentasurveys.com

Appendix H: Survey Equipment Listing

					COBIE Surveys				
Data Collection Tools and Accessories			**Unit Price**	**Unit**	**Paper Forms**	**Acer Laptop**	**Adapx Pen**	**Panasonic U1**	**Reference**
	Laser Measuring Device	Hilti PD 4 Laser Range Meter	$199	Each	X	X	X	X	Hilti Laser Measure (homedepot.com)
	Construction Calculator	Calculated Industries Construction Master 5	$50	Each	X	X	X	X	Construction Calculator (homedepot.com)
	Toolbelt	Poly Suspension Tool Rig	$50	Each	X	X	X	X	Poly Suspension Tool Rig (homedepot.com)
	Portable wheeled cart	Rubbermaid® Metal Fold 'N Roll Cart System, Black	$89	Each	X	X	X	X	Portable Cart (homedepot.com)
	25' metal tape measure	Stanley 25 Ft. Leverlock Tape Measure	$9	Each	X	X	X	X	Metal Tape Measure (homedepot.com)
	LED Flashlight	Gerber Infinity Ultra LED Flashlight	$21	Each	X	X	X	X	Gerber LED Flashlight (rei.com)
	Clipboards, 8.5"x11"		$1	Each	X	X		X	Post Exchange (Army and Air Force Exchange Service)
	Clipboards, 11"x17"		$15	Each	X	X	X	X	11x17.com
	Pens and Mechanical Pencils		$0.50	Each	X	X	X	X	

Data Entry Equipment for Field Conditions			Unit Price	Unit	COBIE Surveys				Reference
					Paper Forms	Acer Laptop	Adapx Pen	Panasonic U1	
	Foldable chair	GCI Outdoor Quik-E-Seat	$29	Each		X		X	GCI Quick-E-Seat (rei.com)
	Foldable table	Personal Table	$28	Each		X		X	Personal Table (campingworld.com)
	Mini mouse for Tablet PC	Logitech Notebook Optical Mouse Plus	$11	Each		X		X	Logitech mini-mouse (wikio.com)

Office Computer		Unit Price	Unit	COBIE Surveys				Reference
				Paper Forms	Acer Laptop	Adapx Pen	Panasonic U1	
Desktop Computer (3.2 Ghz, 1Gb RAM, 80Gb harddrive, onboard graphics card, Windows XP)	OptiPlex 755 Desktop	$1,325	Each	X		X		OptiPlex (http://configure.us.dell.com)
Video Card for 3D Modeling	PNY Technologies - PNY NVIDIA Quadro FX 4000 SDI	$5,067	Each	(only if computer also used for 3D modeling)				PNY NVIDIA Quadro FX 4000 (google.com)
17" flat screen	Dell 17 inch E178FP Flat Panel, Analog	$199	Each	X		X		Dell 17-in Flatscreen (http://configure.us.dell)
3-Yr IT Support	3 Year ProSupport for IT and 3 Year 4HR 7x24 Onsite Service	$149	Lump Sum	X		X		3-Yr IT Support (http://configure.us.dell.com)
Color Laser Printer	Lexmark C920	$1,713	Each	X		X		Lexmark C920 (google.com)

Computer Printing		Unit Price	Unit	COBIE Surveys Paper Forms	Acer Laptop	Adapx Pen	Panasonic U1	Reference
Laser printer toner - cyan	Lexmark C920 Cyan Toner Cartridge	$310	Each			X		Lexmark C920 Cyan Toner (cdwg.com)
Laser printer toner - magenta	Lexmark C920 Magenta Toner Cartridge	$310	Each			X		Lexmark C920 Magenta (www.cdwg.com)
Laser printer toner - yellow	Lexmark C920 Yellow Toner Cartridge	$310	Each			X		Lexmark C920 Yellow (www.cdwg.com)
Laser printer toner - black	Lexmark C920 Black Toner Cartridge	$214	Each	X	X	X	X	Lexmark C920 Black (www.cdwg.com)
Color Prints - 8.5" x 11"	Yield: Up to 14,000 pages based on approx 5% coverage	$0.08	Each 8.5x11					
Color prints - 11" x 17"	Yield: Up to 7,500 pages based on approx 5% coverage	$0.16	Each 11x17			X		
B/W Prints - 8.5" x 11'	Yield: Up to 15,000 pages based on approx 5% coverage	$0.01	Each 8.5x11	X	X		X	
B/W Prints - 11" x 17"	Yield: Up to 7,500 pages based on approx 5% coverage	$0.03	Each 11x17	X	X		X	

Technology Specific COBIE Equipment			Unit Price	Unit	COBIE Surveys Paper Forms	Acer Laptop	Adapx Pen	Panasonic U1	Reference
	ACER notebook	Travelmate C300 - TMC301XCi	$2,017	Each		X			Acer Travelmate C300 (acersupport.com)
	Capturx for Excel single license	Capturx for MS Office Excel 2007	$1,800	Each			X		
	One Note Set w/Adapx digital pen	Capturx for MS Office OneNote 2007 Kit	$349	Each			X		Capturx for OneNote (adapx.com)
	Replacement digital pen	Adapx Digital Pen Replacement	$250	Each			X		Adapx Digital Pen Replacement (adapx.com)
	MS One Note single license	Microsoft OneNote 2007	$99	Each			X		MS OneNote 2007 (adapx.com)
	Replacement Ink	Digital Penx ink refill cartridges - 5 pack	$10	Each			X		Digital Pen Ink Refill Cartridges (adapx.com)
	Ultra-Mobile PC	Panasonic Toughbook U1 Fully Rugged UMPC	$2,499	Each				X	Panasonic U1 (http://catalog2.panasonic.com)

Additional Equipment Items	Unit	Unit	Contract	In	Alt	Reference

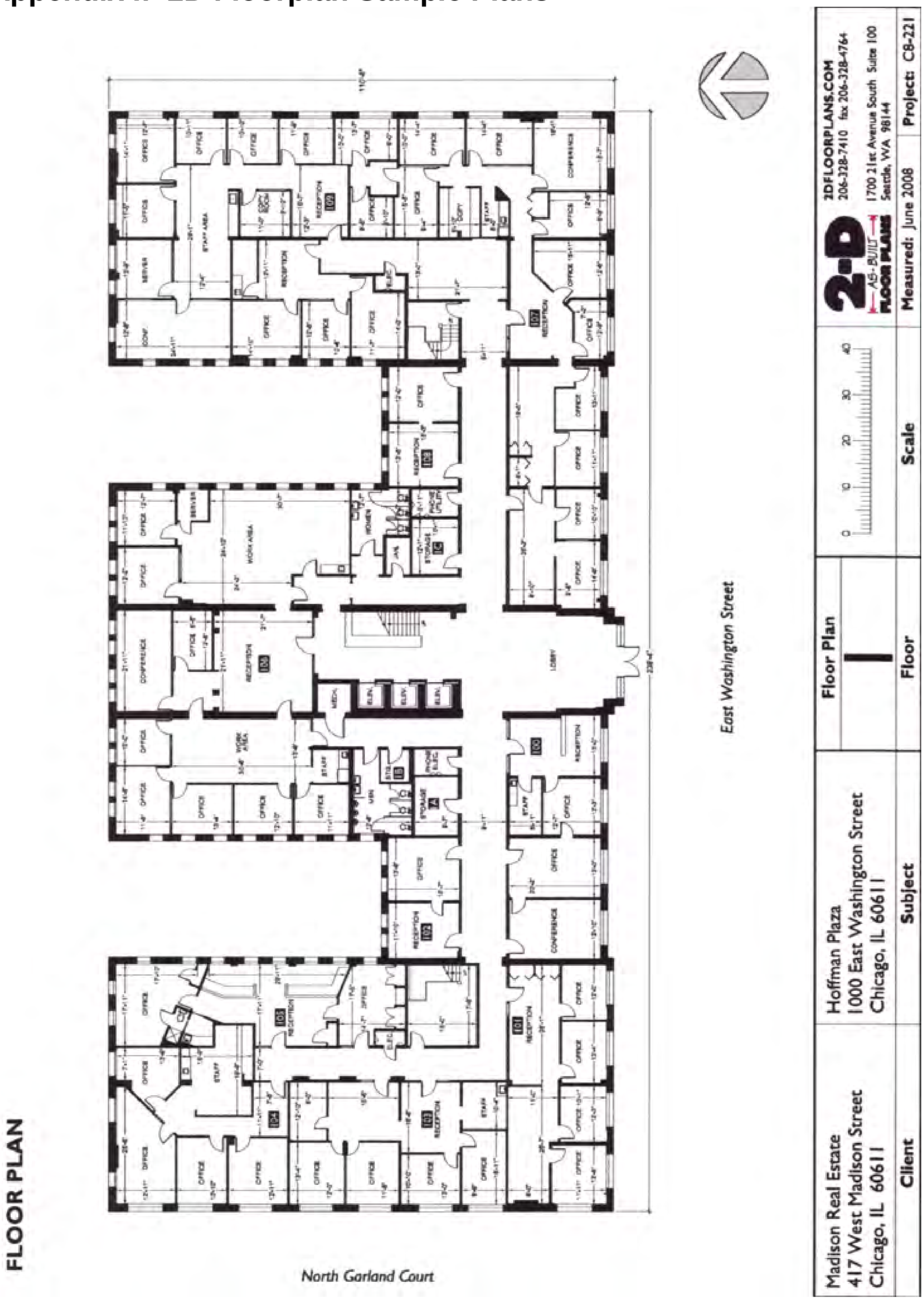
		Price		Service		House	COBIE Tools	
Tablet Notebook Options				**2D**	**3D**	**3D***		
	Panasonic Toughbook-19 (Fully rugged) o Genuine Windows Vista® Business o CPU Intel® Core™ 2 Duo Mobile Processor U7500 o 5.1 pounds o 10.4" daylight readable LCD o 1024 MB SDRAM (DDR2) standard, expandable to 4096MB o Integrated Bluetooth wireless o Storage 80 GB HDD	$3,500	Each			* Note: Requires Office Computer with the special video card	X	Panasonic Toughbook-19 (http://catalog2.panasonic.com)
	LifeBook P1620 o Genuine Windows Vista® Business o Intel® Core™ 2 Duo Processor Ultra Low Voltage U7600 (1.20 GHz, 2 MB L2 cache, 533 MHz FSB) o 2.2 pounds o Microsoft® Office OneNote® 2007 o 8.9" WXGA touchscreen display o One Micro-DIMM slot; min. 512 MB; max. 2 GB DDR2 SDRAM o Integrated Bluetooth wireless o Storage 80GB HDD	$2,200	Each	X				Fujitsu Lifebook (http://store.shopfujitsu.com)

Additional Equipment Items		Unit Price	Unit	Contract Service		In House	Alt COBIE Tools	Reference
Laser Measuring Tools				**2D**	**3D**	**3D***		
	Leica Disto A6 Laser Distance Meter o Measuring range of 0.05 up to 200m (0.16 up to 650ft) o Measure long distances (approx. 100m) w/o target plate o Integrated viewfinder w/2x magnification o Integrated BLUETOOTH® technology o DISTO™ transfer Free software which sends the measured values reliably to Excel®, Word®, AutoCad® and many other softwares	$650	Each	X				Leica Laser Distance Meter (leica-geosystems.com)
	Stanley Fatmax Tru Laser Measurer o Measuring range 100 feet with a +/- 1/4" o Area measuring, distance measuring and calculator o Single point and push on measurement	$99	Each				X	Stanley Fatmax Laser Measure (acehardware.com)

Additional Equipment Items		Unit Price	Unit	Contract Service 2D	Contract Service 3D	In House 3D*	Alt COBIE Tools	Reference
Laser Scanning and Associated Technologies/Software								
High-speed Laser Scanner	Leica ScanStation 2	$150,000	Each		X			Leica ScanStation 2 (leica-geosystems.com)
	Leica HDS6000	$150,000	Each		X			Leica HDS6000 (leica-geosystems.com)
Total Station	Leica TP S800	$10,000	Each		X			Total Station, Leica (leica-geosystems.com)
Leica Maintenance Service		$10,000	per Year		X			
Camera, 12 Megapixel	Canon Powershot G9	$395	Each		X			Recommended by Leica - see Total Station site
	Canon Powershot A650 IS	$295	Each		X			Recommended by Leica - see Total Station site
Camera mount for 360-degree photos	0-360 Panoramic Optic™	$600			X			0-360 Panoramic Optic (0-360.com)
Drawing Plug-in for AutoCAD	Leica fieldPro	Ranken Survey, Seattle, (206) 762-3951		X				Leica fieldPro: Survey in CAD (leica-geosystems.com)
Point Cloud Processing	Cyclone Software License	$13,000	per License		X	X		Cyclone Data Sheet (leica-geosystems.com)
3D Modeling Software, CAD plug-in	Cloudworx	$1,500	per License		X	X		Leica CloudWorx for AutoCAD Data Sheet (leica-geosystems.com)
3D Review Software	Leica TruView	0	freeware		X	X		Leica TruView and Publisher Data Sheet (leica-geosystems.com)

Additional Equipment Items	Unit Price	Unit	Contract Service 2D	Contract Service 3D	In House 3D*	Alt COBIE Tools	Reference
Additional Cart/Carrying Options							
H. Wilson 26" Plastic Utility Cart, Putty	$100	Each				X	Wilson 26-in Utility Cart (officedepot.com)
Wheeled Briefcase	$53	Each				X	Wheeled Briefcase (officedepot.com)
Rubbermaid® Janitor Cart With Zipper Vinyl Bag	$196	Each				X	Rubbermaid Janitor Cart (officedepot.com)
Safco® Rolling Cart, Letter/Legal, Black	$40	Each				X	Safco Rolling Cart (officedepot.com)
Additional Mobile Table Options							
Universal Table	$20	Each				X	Universal Table (campingworld.com)
Quik-Fold Tag Along Table	$10	Each				X	Quik-Fold Table (campingworld.com)
Safco® Wave Deskside Printer Stand,	$104	Each				X	Safco Wave Printer Stand (officedepot.com)
Additional Foldable Chair Options							
Mesh Beach Chair	$20	Each				X	Mesh Beach Chair (officedepot.com)
The Deluxe Chair	$34	Each				X	Deluxe Chair (officedepot.com)
Captain's Chair	$18	Each				X	Captain's Chair (officedepot.com)

Appendix I: 2D Floorplan Sample Plans



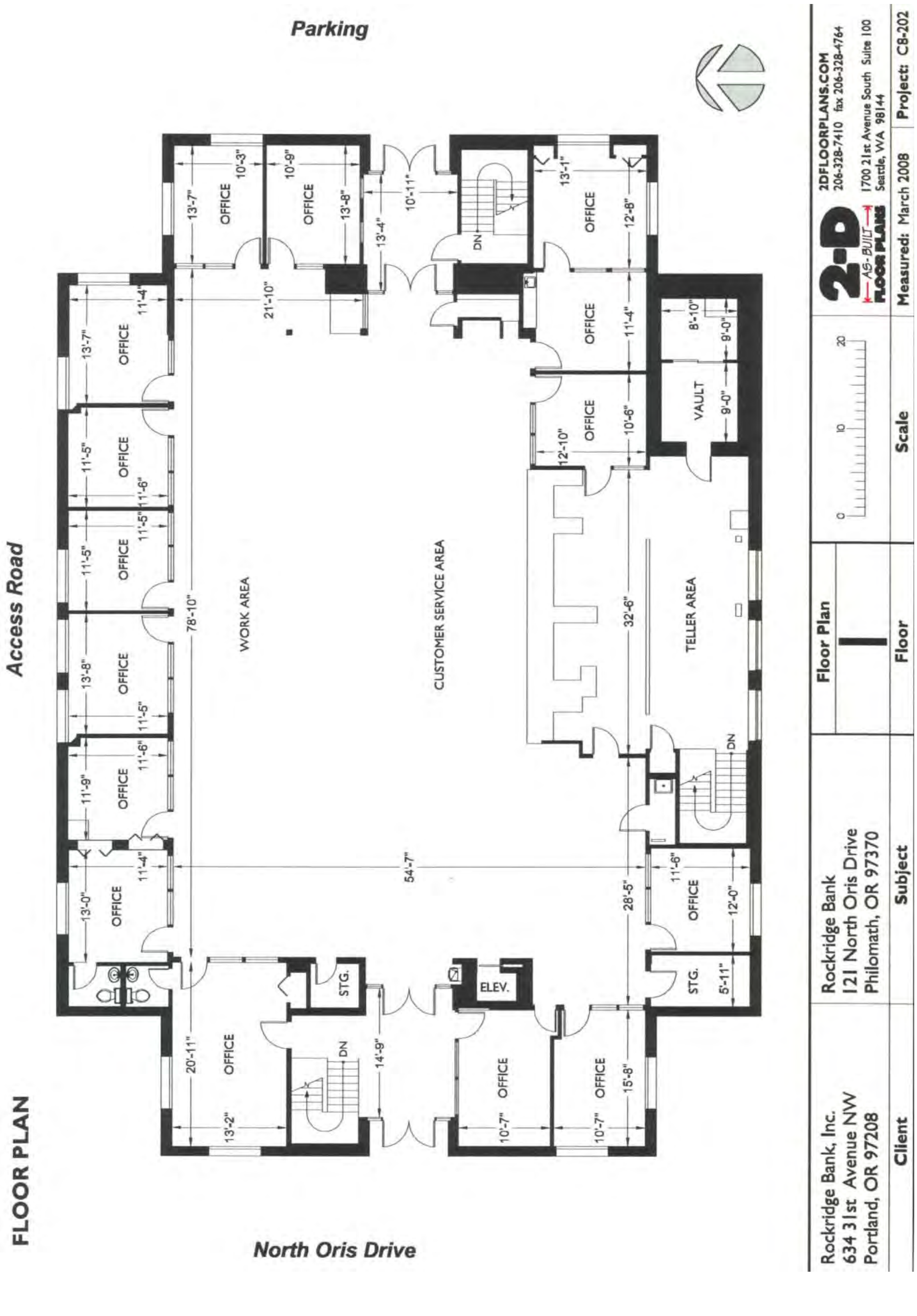
LEASE PLAN

Floor Summary	SQ. FT.
Total Rentable	20,575
Total Usable	16,544
Combined R/U	1.2436
Floor Common	3,630
Building Common	1,033
Total Vertical	854

Suite #	Usable	Rentable
Suite 100	1,095	1,362
Suite 101	1,155	1,436
Suite 102	415	516
Suite 103	1,296	1,612
Suite 104	1,292	1,607
Suite 105	1,090	1,356
Suite 106	3,522	4,380

Suite #	Usable	Rentable
Suite 107	3,195	3,475
Suite 108	401	499
Suite 109	2,794	3,475
Suite A Storage	124	154
Suite B Storage	43	53
Suite C Storage	122	152

Client	Subject	Floor	Scale	
Madison Real Estate 417 West Madison Street Chicago, IL 60611	Hoffman Plaza 1000 East Washington Street Chicago, IL 60611	Lease Plan 1	0 10 20 30 40	2-D AS-BUILT FLOOR PLANS 2DFLOORPLANS.COM 206-328-7410 fax 206-328-4764 1700 21st Avenue South Suite 100 Seattle, WA 98144 Measured: June 2008 Project: C8-221


FLOOR PLAN
Parking
Access Road
North Oris Drive
WORK AREA
CUSTOMER SERVICE AREA
TELLER AREA
VAULT
OFFICE
STG.
ELEV.
DN
78'-10"
54'-7"
32'-6"
28'-5"
21'-10"
Rockridge Bank, Inc.
634 31st Avenue NW
Portland, OR 97208
Client
Rockridge Bank
121 North Oris Drive
Philomath, OR 97370
Subject
Floor Plan
Floor
Scale
2DFLOORPLANS.COM
206-328-7410 fax 206-328-4764
1700 21st Avenue South Suite 100
Seattle, WA 98144
AS-BUILT FLOOR PLANS
Measured: March 2008
Project: C8-202

FURNITURE PLAN
Parking
Access Road
North Oris Drive
DN
DN
DN
Rockridge Bank, Inc.
634 31st Avenue NW
Portland, OR 97208
Client
Rockridge Bank
121 North Oris Drive
Philomath, OR 97370
Subject
Furniture Plan
Floor
0 10 20
Scale
2-D
AS-BUILT
FLOOR PLANS
2DFLOORPLANS.COM
206-328-7410 fax 206-328-4764
1700 21st Avenue South Suite 100
Seattle, WA 98144
Measured: March 2008
Project: CB-202

ELECTRICAL PLAN

LEGEND			
OUTLET SINGLE	DUPLEX OUTLET SWITCH	S SINGLE SWITCH	THERMOSTAT
OUTLET DUPLEX	FLOOR OUTLET	S_2 DOUBLE SWITCH	ELECTRICAL PANEL
OUTLET QUAD	DATA OUTLET	SPEAKER	PHONE JACK

Client	Subject	Floor	Scale	
Rockridge Bank, Inc. 634 31st Avenue NW Portland, OR 97208	Rockridge Bank 121 North Oris Drive Philomath, OR 97370	Electrical Plan 1	0 10 20 30	2-D AS-BUILT FLOOR PLANS 2DFLOORPLANS.COM 206-328-7410 fax 206-328-4764 1700 21st Avenue South Suite 100 Seattle, WA 98144
				Measured: March 2008 — Project: C8-202

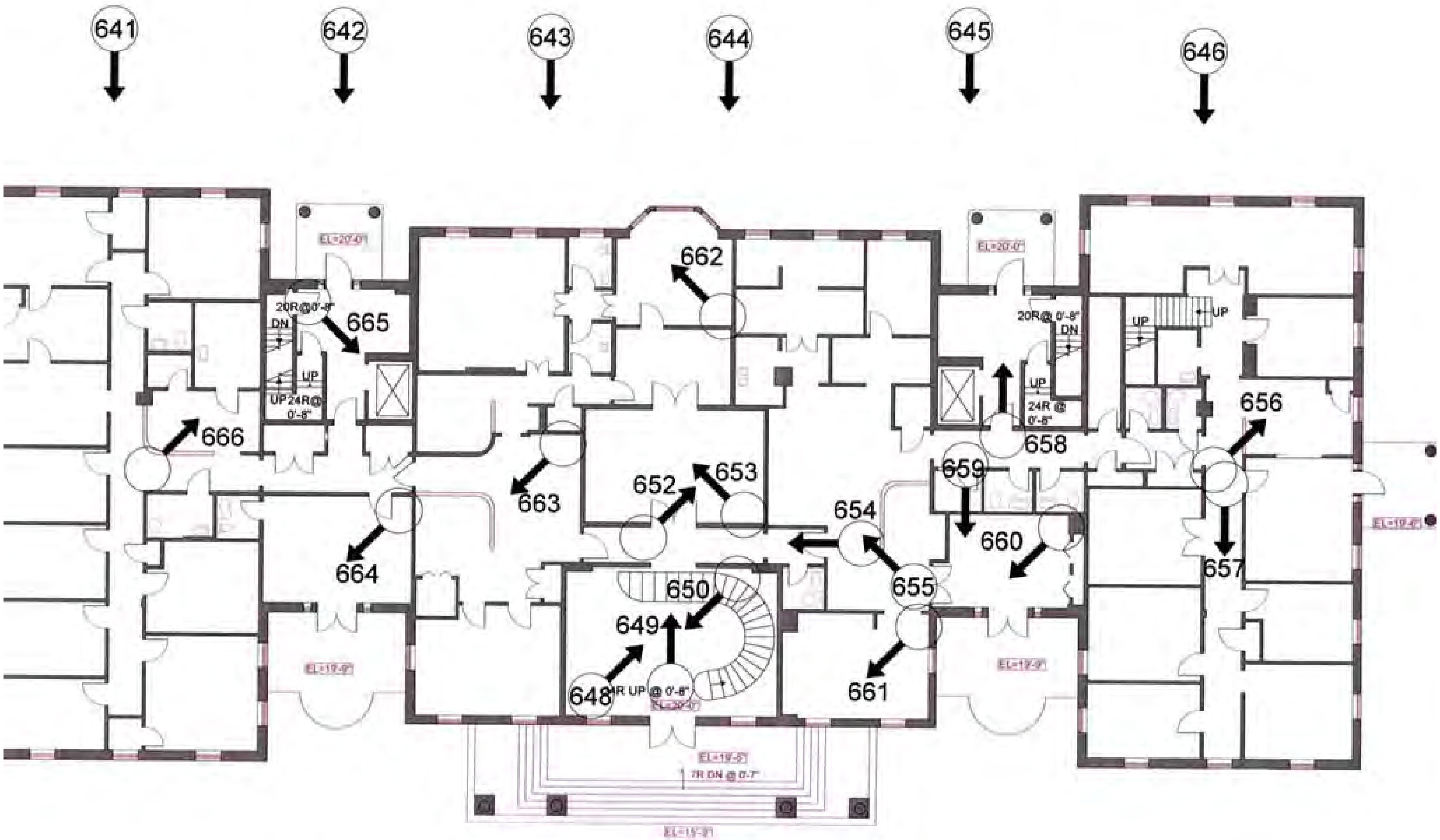
REFLECTED CEILING PLAN

LEGEND

2 X 2 SUPPLY DIFFUSER	2 X 4 FLUORESCENT LIGHT	EMERGENCY EXIT LIGHT
2 X 2 RETURN DIFFUSER	2 X 2 FLOURESCENT LIGHT	FIRE STROBE
HEAT DETECTOR	RECESSED CAN LIGHT	

Client	Subject	Floor	Scale	
Rockridge Bank, Inc. 634 31st Avenue NW Portland, OR 97208	Rockridge Bank 121 North Oris Drive Philomath, OR 97370	Reflected Ceiling Plan 1	0 10 20	2-D AS-BUILT FLOOR PLANS 2DFLOORPLANS.COM 206-328-7410 fax 206-328-4764 1700 21st Avenue South Suite 100 Seattle, WA 98144 Measured: March 2008 Project: C8-202

PHOTO KEYMAP



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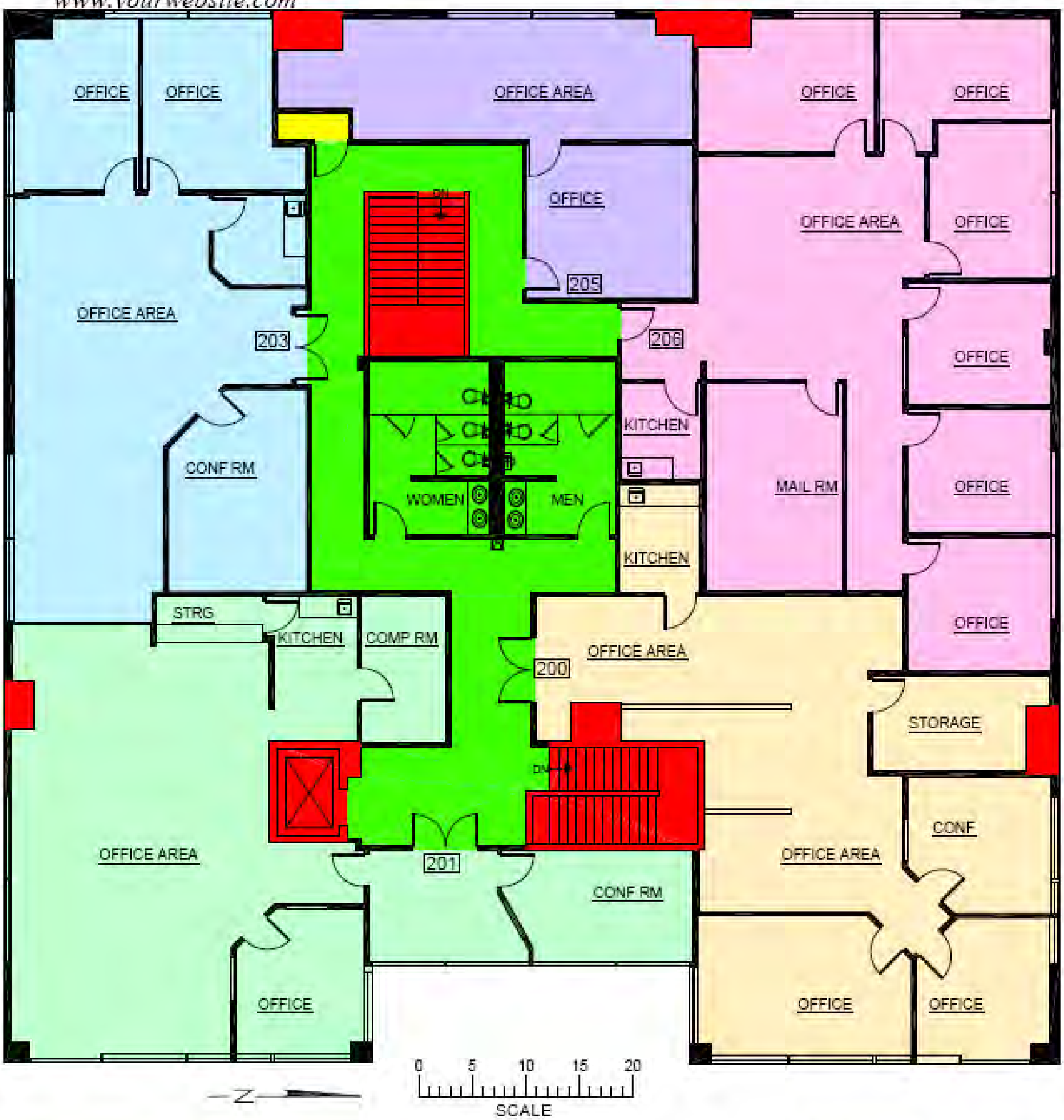
LEASE PLAN

123 AIRPORT WAY
SOMEWHERE, XX

SECOND FLOOR

(As Measured: March 2002)



FLOOR SUMMARY	SQ.FT.
Total Rentable	9,333
Total Usable	7,539
Combined R/U	1.2380
Floor Common	1,281
Building Common	20
Total Vertical	484

Suite #	Usable	Rentable
200	1,608	1,990
201	1,759	2,178
203	1,506	1,865
205	649	803
206	2,017	2,497

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FILE: 00-999

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FAX (987) 123-4568
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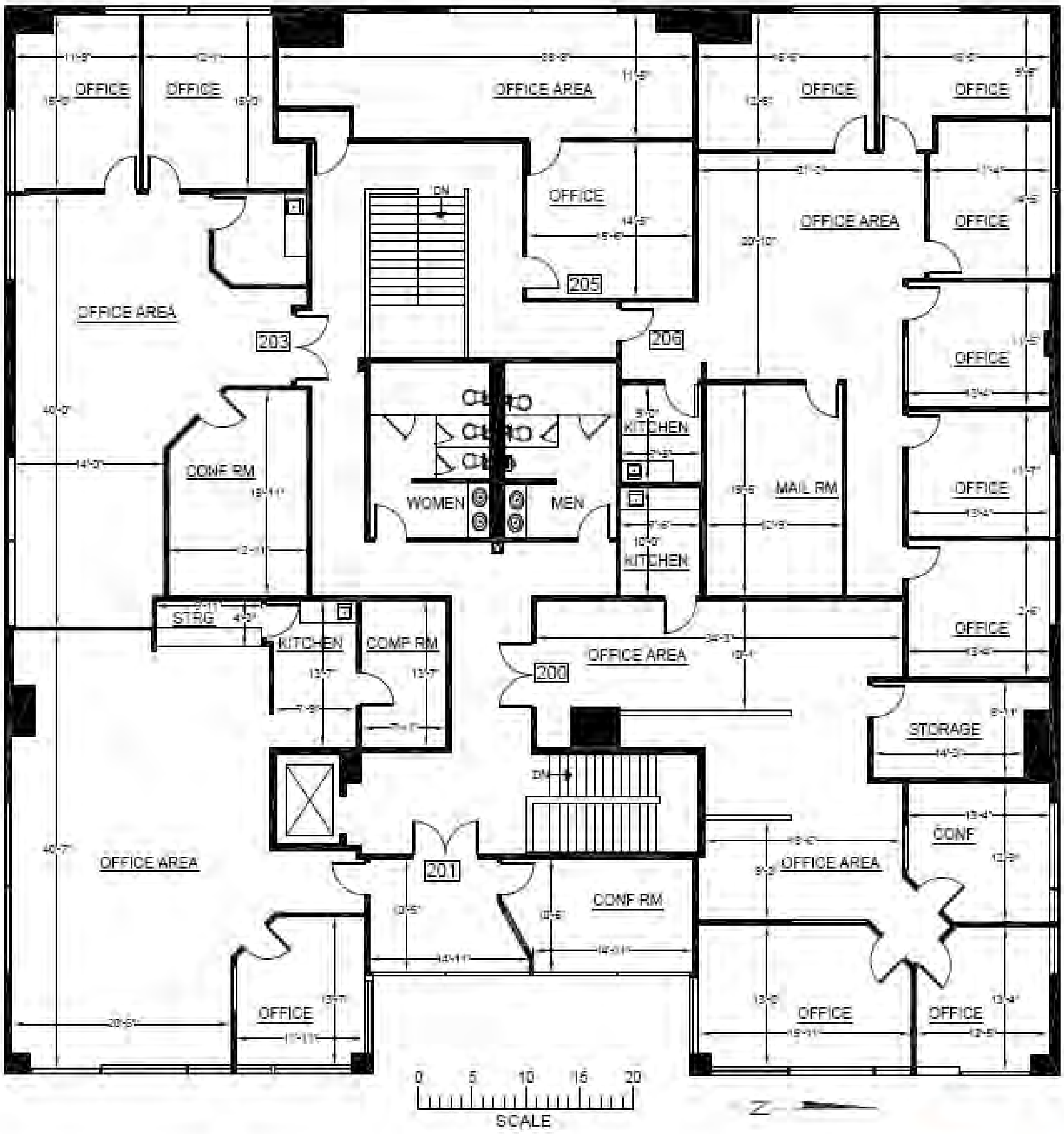
123 AIRPORT WAY
SOMEWHERE, XX

SECOND FLOOR

(As Measured: March 2002)



TEL: (888) 393-6655
FILE: 00-999

Appendix J: 2D and 3D Cost Calculations

Bldgs 9137		Width (ft)	Length (ft)	Height (ft)	# of RM.	SF/Mech	Sq Ft
	External Dimensions	55.25	217.45	34.45			
	1st Floor	53.15	215.35		124	607.52	11,446.00
	2nd Floor	53.15	215.35		128		11,446.00
	3rd Floor	53.15	215.35		128		11,446.00
	Mechanical Space	(Rectangular, densely equipped space)					**607.52**
	Total Occupied Space						**33730.48**

	2D Floorplans - Contract Service (Cost Ranges)												
	Interior Floorplan		**AutoCad***	**Elec/Comm Plan**		**AutoCad**	**Interior Heights**		**AutoCad**	**Reflective Ceiling**		**AutoCad**
	low	*high*		*low*	*high*		*low*	*high*		*low*	*high*	
	($0.06/sf)	($0.08/sf)	($150/sheet)	($0.02/sf)	($0.03/sf)	($150/sheet)	($0.01/sf)	($0.02/sf)	($150/sheet)	($0.04/sf)	($0.07/sf)	($150/sheet)
Occupied Space	$2,024	$2,698	$450	$675	$1,012	$450	$337	$675	$450	$1,349	$2,361	$450
Mechanical Space			* Assuming 1 sheet per floor									
SUBTOTAL (Per Item)	$2,024	$2,698	$450	$675	$1,012	$450	$337	$675	$450	$1,349	$2,361	$450

	3D Scanning/Modeling - Contract Service (Cost Ranges)								In-House 3D Modeler (Cost Ranges)				BIM Technician (Cost Ranges)			
	Scans		**Scanning and TruView**		**Detailed 3D Model**		**Skeleton 3D Model**		**Est Working Days**		**Skeleton 3D Model**		**Est Working Days**		**COBIE/Model Integration**	
	low	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*
Occupied Spaces	8	10	$4,500	$5,000	$15,000	$20,000	$9,000	$15,000	4	7	$1,250	$2,188	5	10	$1,042	$2,083
Mechanical Space	6	10	$3,000	$4,000	$18,000	$25,000	$6,000	$12,000	5	8	$1,563	$2,500				
SUBTOTAL (Per Item)	14	20	$7,500	$9,000	$33,000	$45,000	$15,000	$27,000	9	15	$2,813	$4,688	5	10	$1,042	$2,083

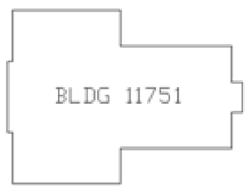
GRAND TOTAL (Cost Range)	$16,497	$22,234
(Assumes Full-time In-House 3D Modelerer)		

Bldgs 3218			Width (ft)	Length (ft)	Height (ft)	# of RM.	SF/Mech	Sq Ft
	External Dimensions		38.833	217.667	37.91			
		Basement	36.83	215.68		11		7944.03
	Main	1st Floor	36.83	215.68		36		7944.03
		2nd Floor	36.83	215.68		41		7944.03
		3rd Floor	36.83	215.68		41		7944.03
	Extend01	Basement	33.5	76.833		1	800.65	2573.91
		1st Floor	33.5	76.833				2573.91
	Extend02	Basement	33.5	52.1667		2		1747.58
		1st Floor	33.5	52.1667				1747.58
		Mechanical Space	(Rectangular, open space; sparsely equipped)					**800.65**
		Total Occupied Space						**39618.45**

	2D Floorplans - Contract Service (Cost Ranges)												
	Interior Floorplan		AutoCad*	Elec/Comm Plan		AutoCad	Interior Heights		AutoCad	Reflective Ceiling		AutoCad
	low	*high*		*low*	*high*		*low*	*high*		*low*	*high*	
	($0.06/sf)	($0.08/sf)	($150/sheet)	($0.02/sf)	($0.03/sf)	($150/sheet)	($0.01/sf)	($0.02/sf)	($150/sheet)	($0.04/sf)	($0.07/sf)	($150/sheet)
Occupied Space	$2,377	$3,169	$600	$792	$1,189	$600	$396	$792	$600	$1,585	$2,773	$600
Mechanical Space			* Assuming 1 sheet per floor									
SUBTOTAL (Per Item)	$2,377	$3,169	$600	$792	$1,189	$600	$396	$792	$600	$1,585	$2,773	$600

	3D Scanning/Modeling - Contract Service (Cost Ranges)								In-House 3D Modeler (Cost Ranges)				BIM Technician (Cost Ranges)			
	Scans		Scanning and TruView		Detailed 3D Model		Skeleton 3D Model		Est Working Days		Skeleton 3D Model		Est Working Days		COBIE/Model Integration	
	low	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*
Occupied Spaces	8	10	$4,500	$5,000	$15,000	$20,000	$9,000	$15,000	4	7	$1,250	$2,188	5	10	$1,042	$2,083
Mechanical Space	4	8	$2,700	$3,000	$13,500	$20,000	$5,400	$9,000	4	7	$1,250	$2,188				
SUBTOTAL (Per Item)	12	18	$7,200	$8,000	$28,500	$40,000	$14,400	$24,000	8	14	$2,500	$4,375	5	10	$1,042	$2,083

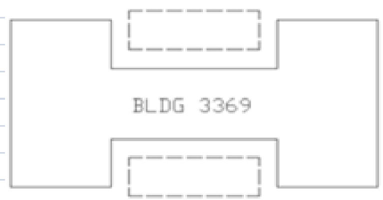
GRAND TOTAL (Cost Range)	$17,250	$22,699
(Assumes Full-time In-House 3D Modelerer)		

Bldgs 11751			Width (ft)	Length (ft)	Height (ft)	# of RM.	SF/Mech	Sq Ft
	External Dimensions		71.95	93.57	28.00			
			71.98	121.23	28.00			
	Main	1st Floor	70.23	91.27		22	456.62	6409.77
		2nd Floor	70.23	91.27		46		6409.77
	Storage	1st Floor	70.26	118.93		1		8355.96
		2nd Floor				1		3285.90
		Mechanical Space	(Rectangular, densely equipped space)					**456.62**
		Total Occupied Space						**24004.78**

	2D Floorplans - Contract Service (Cost Ranges)											
	Interior Floorplan		AutoCad*	Elec/Comm Plan		AutoCad	Interior Heights		AutoCad	Reflective Ceiling		AutoCad
	low	*high*		*low*	*high*		*low*	*high*		*low*	*high*	
	($0.06/sf)	($0.08/sf)	($150/sheet)	($0.02/sf)	($0.03/sf)	($150/sheet)	($0.01/sf)	($0.02/sf)	($150/sheet)	($0.04/sf)	($0.07/sf)	($150/sheet)
Occupied Space	$1,440	$1,920	$300	$480	$720	$300	$240	$480	$300	$960	$1,680	$300
Mechanical Space			* Assuming 1 sheet per floor									
SUBTOTAL (Per Item)	$1,440	$1,920	$300	$480	$720	$300	$240	$480	$300	$960	$1,680	$300

	3D Scanning/Modeling - Contract Service (Cost Ranges)								In-House 3D Modeler (Cost Ranges)				BIM Technician (Cost Ranges)			
	Scans		Scanning and TruView		Detailed 3D Model		Skeleton 3D Model		Est Working Days		Skeleton 3D Model		Est Working Days		COBIE/Model Integration	
	low	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*
Occupied Spaces	8	10	$4,000	$4,500	$15,000	$20,000	$8,000	$13,500	4	7	$1,250	$2,188	5	10	$1,042	$2,083
Mechanical Space	4	6	$3,000	$4,000	$18,000	$25,000	$6,000	$12,000	5	8	$1,563	$2,500				
SUBTOTAL (Per Item)	12	16	$7,000	$8,500	$33,000	$45,000	$14,000	$25,500	9	15	$2,813	$4,688	5	10	$1,042	$2,083

GRAND TOTAL (Cost Range)	$14,133	$19,188
(Assumes Full-time In-House 3D Modeler)		

Bldgs 3369		Width (ft)	Length (ft)	Height (ft)	# of RM.	SF/Mech	Sq Ft
	External Dimensions	137.42	273.58	28.00			
	1st Floor				32	803.53	24895.69
	2nd Floor				47		5286.64
	Mechanical Space	(Rectangular, densely equipped space)					803.53
	Total Occupied Space						29378.81

	2D Floorplans - Contract Service (Cost Ranges)												
	Interior Floorplan		AutoCad*	Elec/Comm Plan		AutoCad	Interior Heights		AutoCad	Reflective Ceiling		AutoCad
	low	*high*		*low*	*high*		*low*	*high*		*low*	*high*	
	($0.06/sf)	($0.08/sf)	($150/sheet)	($0.02/sf)	($0.03/sf)	($150/sheet)	($0.01/sf)	($0.02/sf)	($150/sheet)	($0.04/sf)	($0.07/sf)	($150/sheet)
Occupied Space	$1,763	$2,350	$900	$588	$881	$900	$294	$588	$900	$1,175	$2,057	$900
Mechanical Space			* Assuming 1 sheet per floor & major section									
SUBTOTAL (Per Item)	$1,763	$2,350	$900	$588	$881	$900	$294	$588	$900	$1,175	$2,057	$900

	3D Scanning/Modeling - Contract Service (Cost Ranges)								In-House 3D Modeler (Cost Ranges)				BIM Technician (Cost Ranges)			
	Scans		Scanning and TruView		Detailed 3D Model		Skeleton 3D Model		Est Working Days		Skeleton 3D Model		Est Working Days		COBIE/Model Integration	
	low	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*	*low*	*high*
Occupied Spaces	16	20	$8,000	$10,000	$30,000	$40,000	$16,000	$30,000	5	8	$1,563	$2,500	5	10	$1,042	$2,083
Mechanical Space	6	10	$3,000	$4,000	$20,000	$28,000	$6,000	$12,000	5	8	$1,563	$2,500				
SUBTOTAL (Per Item)	22	30	$11,000	$14,000	$50,000	$68,000	$22,000	$42,000	10	16	$3,125	$5,000	5	10	$1,042	$2,083

GRAND TOTAL (Cost Range)	**$21,544**	**$28,476**
(Assumes Full-time In-House 3D Modelerer)		

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August 2010	Final	

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W9132T-08-2-0020

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6. AUTHOR(S)
Eddy Rojas, Carrie Dossick, and John Schaufelberger

5d. PROJECT NUMBER

5e. TASK NUMBER

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University of Washington
Department of Construction Management
Seattle, WA 98195

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Facilities Branch (DAIM-ODF)
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14. ABSTRACT
The operation and maintenance of U.S. Army real property could greatly benefit from the availability of advanced forms of digital as-built facility data, such as those used in Building Information Modeling (BIM) systems. The Army Corps of Engineers requires the use of BIM on all new construction projects associated with the Army Standardization program. However, new construction typically accounts for only a small proportion of an installation's real property assets. Current BIM technology is capable of capturing existing facility data, but developing models for all existing facilities is not feasible because of the cost. As an alternative to developing complete models for existing facilities, a subset of BIM data could be developed to capture the data needed to improve the cost-effectiveness of operating and maintaining existing facilities. The University of Washington was contracted by the U.S. Army Research and Development Center under the Installation Technology Transfer Program to perform a comparative analysis of different methodologies for capturing as-built BIM data for existing facilities at Fort Lewis, WA. This report provides the results of that analysis.

15. SUBJECT TERMS
Building Information Models (BIM), operations and maintenance (O&M), facilities, cost-effectiveness, modeling

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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